Development of Aviation Pesticide Spraying in Agriculture During Japan's Period of High Economic Growth: A Focus on MAVs Prior to the Establishment of UAVs

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Abstract

This study explored the development of manned aerial vehicles (MAVs) for pesticide spraying in agriculture during Japan's period of high economic growth, setting the foundation for future unmanned aerial vehicles (UAVs or drones). The study examined how the unique demands of Japan's agriculture, including geographical and operational requirements, fostered the transition from fixed-wing aircraft (airplanes) to rotary-wing aircraft (helicopters) and drove "incremental" and "induced" innovation processes focusing on MAV innovations. These innovations were supported by Japan's plant protection system, facilitated by the Ministry of Agriculture and Forestry, and realized through collaborations with the aviation and manufacturing industries. The Japan Agricultural Aviation Association (JAAA), in partnership with public and private entities, has advanced aerial pesticide spraying to meet the increasing agricultural demands by incorporating low-volume spraying technology and adapting apparatus designs. However, by the early 1980s, MAV pesticide spraying faced profitability and safety challenges, which prompted the JAAA to explore UAVs as an alternative. This study highlights the interrelationship between the agricultural and non-agricultural sectors in advancing agricultural technology and underscores the incremental evolution of MAVs that paved the way for the UAVs era in agricultural spraying.

Introduction

This study examines the innovation in aviation pesticide spraying in agriculture during Japan's period of high economic growth by focusing on manned aerial vehicles (MAVs) prior to the establishment of unmanned aerial vehicles (UAVs). The MAVs and UAVs mentioned herein are based on the classification presented in Figure 1. In general, MAVs are manned airplanes of fixed-wing aircraft and manned aircraft of rotary-wing aircraft (helicopters), whereas UAVs (commonly known as drones) are unmanned aircraft of rotary-wing aircraft (unmanned helicopter and multicopter) and unmanned airplanes of fixed-wing aircraft.

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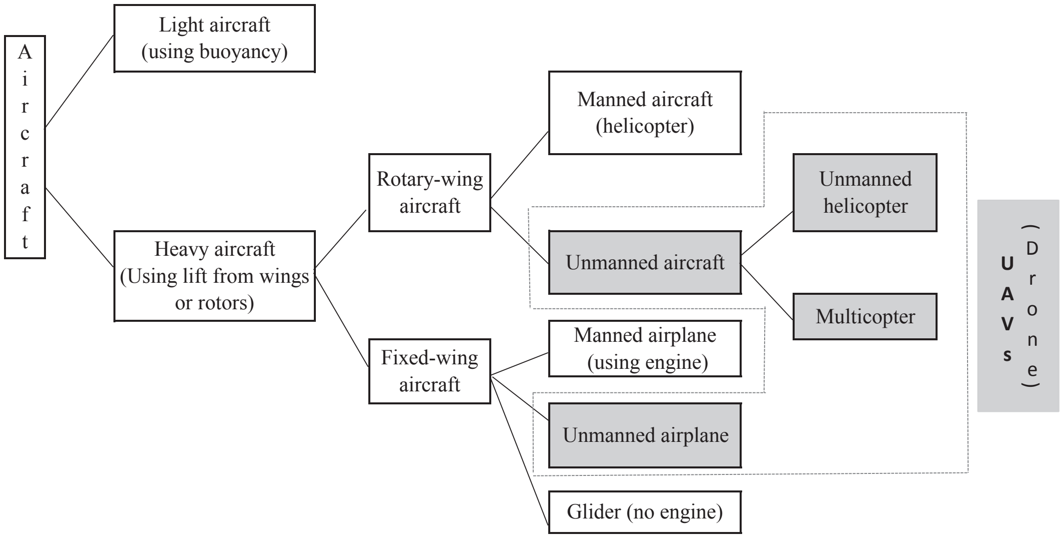

Figure 1. Aircraft classification

Source: Shinji Suzuki 2017, *Doron ga hiraku mirai no sora (The sky of the future opened up by Drones)*, Kagaku Doujin, pp. 36-38. Asustin Choi-Fitzpatrick 2014, "Drones for Good: Technological Innovations, Social Movements, and the State," *Journal of International Affairs*, 68-1, p19. Erdal Ozkan 2024. "Drones for Spraying Pesticides: Opportunities and Challenges." *Ohioline (Ohio State University Extension)*. Accessed August 15, 2024. https://ohioline.osu.edu/factsheet/fabe-540.

Recent, studies have increasingly evaluated the historical experience of Japanese industrial UAVs or drones because of their advanced use in pesticide spraying and the role of related industry associations in the development of legislation (Peter van Blyenburgh 1999; Brad Bolman 2015; Kaitlin D. Sheets 2018; Fernando, Wieke, Zhaodan and Elvira 2020; Erdal Ozkan 2024). Japan has played a significant role in the development and implementation of UAV technology in East Asia, including South Korea and China, since the early 2010s (Xiongkui, Yajia, Jiangli, Aijun and Jing 2014; He, Jane, Andreas, Jan 2017; Yin, Lan, Wen, Deng, Zhang and Zhang Jiantao 2018). Among these studies, the origin of commonly pointed-out Japanese UAVs was the model R50, the world's first agricultural UAV, developed and launched by Yamaha Motor in the early 1980s. In this context, the use of UAVs in Japanese agriculture should be positioned as a typical innovation.

For example, Table 1 indicates that among UAVs manufacturers in 19 countries around the world in 1999, Japan, "as an exception" (Peter van Blyenburgh 1999, 5), specialized in agricultural UAVs with the airframe of VTOL (vertical take-off and landing=hericopter), whereas almost all countries, including the United States (US), France, Germany, Israel, and the United Kingdom, primarily used UAVs for military purposes such as surveillance, reconnaissance, and targets acquisition, with the exception of a small number of commercial and meteorological research. The question of why Japan's UAVs specialized in agriculture is critical when exploring the history of innovation. As Brad Bolman (2015) emphasized, "the rhetoric of a "drone transformation" in agriculture, which has pummeled American media over the last few years, is largely absent from Japanese media, in part because unmanned agriculture hit East Asia two decades before its big splash in the United States." In fact, even in Japan, there is a paucity of research on the detailed historical innovation process of UAVs for pesticide spraying. In this study, to clarify the history

Table 1. Overview of current UAVs manufacturers

No.	Country	Manufacturer	System	Airframe	Category	Application
1	Australia	Aerosonde Robotic Aircraft	Aerosonde	FW	LAE	Meteorology & research
		British Aerospace Australia	Nulka	VTOL	Decoy	Decoy
2	Austria	Schlebel Elektron. Gerate	Camcopter	VTOL	CR	RSTA, mine detection
3	Brazil	Gyron Sistemas Autonomos	Helix	VTOL	CR	RSTA
4	Canada	Bombardier-Canadair	CL327 & 427	VTOL	MR	RSTA, comms relay
5	Czech Republic	Vtul a Pul	Sojka III	FW	SR	Recon/Surveillance
6	France	Aerospatiale Matra	CL289	HSSW	LADP	Recon/Surveillance
			Hussard	FW	CR	FOG RSTA
		Altac Industries	S-Mart	FW	SR	RSTA
		CAC syatemes	FoxAT&TX	FW	SR	RSTA
			K100	FW	LETH	Anti-vehicle & structure
			Heiot	VTOL	SR	RSTA
		Evnol Images	Unnamed	VTOL	MINI	Commercial
		Matra Bae Dynamics	Dragon	FW	SR	EW
		Sagem	Crecerelle	FW	SR	RSTA & EW
			Marula	FW	LETH	RSTA & EW
			Sperwer	FW	MR	RSTA
			Ugglan	FW	MR	RSTA
		SurveyCopter	SurveyCopter	VTOL	MINI	Commercial
		Techno-Sub Industries	Vigilant 2000	VTOL	CR	Recon/Surveillance
			Vig.-Fuji 5000	VTOL	MR	RSTA
			Vigiplane	FW	CR	Recon/Surveillance
		Thomson-CSF	Camcopter	VTOL	CR	RSTA, mine detection
7	Germany	Dornier	CL289	HSSW	LADP	Recon/Surveillance
			Seamos	VTOL	SR	RSTA, comms relay
		EMT	Luna	FW	CR	RS
		STN Atlas Elektronik	KZO&Tucan	FW	MR	RSTA
			Talfun	FW	LETH	Anti-vehicle & anti-structure
			Mucke	FW	MR	EW
			Mini-Tucan	FW	CR	RSTA
8	Greece	3 Sigma	Nearchos	FW	SR	RSTA
9	India	ADE, Bengalore	Nighant	FW	SR	RSTA
10	Israel	Israeli Aircraft Industries	Scout	FW	SR	RSTA
			Searcher II	FW	MRE	RSTA
			Harpy	FW	LETH	Anti-radar
			Heron	FW	HALE	RSTA
		Sllver Arrow	Micro-V	FW	SR	Recon/Surveillance
			Sniper	FW	MR	RSTA
			Hermes 450S	FW	MRE	RSTA
			Hermes 1500	FW	HALE	RSTA
11	Italy	Meteor (Alenia)	Mirach 20&26	FW	SR	RSTA
			Mirach 100&150	HSSW	LADP	Recon/Surveillance
12	Japan	Fuji Heavy Industries	RPH2	VTOL	MINI	Agriculture
		Kawada	RoboCopter 300	VTOL	MINI	Agriculture
		Kubota Co.	KG200	VTOL	MINI	Agriculture
		Yamaha Motor Co.	R50, R-Max	VTOL	MINI	Agriculture
		Yanmar Agricult. Equipment	KG135II, YH300	VTOL	MINI	Agriculture

No.	Country	Manufacturer	System	Airframe	Category	Application
13	South Africa	ATE	Vulture	FW	SR	Artillery correct
			Super Vulture	FW	MRE	RSTA, EW
		Kentron	Seeker	FW	MR	RSTA
			Lark	FW	LETH	Anti-radar
14	South Korea	Daewoo	BIJO	FW	MR	RSTA
			Arch50	VTOL	MINI	Agriculture
15	Sweden	Scandicraft Systems	Apid	VTOL	SR	RSTA, EW
		Techment	RPG MKI,II,III	VTOL	SR	RSTA
16	Switzerland	Oerlikon-Contraves	Ranger	FW	MR	RSTA
17	Turkey	EES	Kirlangic	FW	SR	RSTA
			Dogan	FW	MR	RSTA
18	UK	Airspeed Airships	AS-100,400,600	L-t-A	MINI	Commercial
		Intora-Firebird	Firebird	VTOL	SR	Various
		Flight Refueling	Raven	FW	SR	RSTA
		GEC-Marconi	Phoenix	FW	SR	RSTA
		Maggitt Aerospace	Phantom	FW	CR	Recon/Surveillance
19	UAS	AAI Corp	Spectre	FW	SR	RSTA
			Shadow200	FW	SR/MR	RSTA
			Shadow400	FW	MR	RSTA
			Shadow600	FW	MRE	RSTA, comms relay
		AeroVironment	Pointer	FW	CR	Recon/Surveillance
		Alliant Techsystems	Outrider	FW	MR	RSTA
		BAI Aerosystems	Exdrone/Dragon	FW	SR	Recon/Surveillance
			Javelin	FW	CR	Recon/Surveillance
		Bell Helicopter Textron	Eagle Eye	VTOL	MR	RSTA, comms relay
		Boeing	Can. Rotor Wing	VTOL	MR	RSTA
			Heliwing	VTOL	MR	RSTA, comms relay
		Freewing Aerial Robotics	Scorpion	STOL	MR	RSTA
		General Atomics	Altus	FW	HALE	Research
			I. GNAT	FW	MALE	RSTA
			Prowler II	FW	MRE	RSTA
			Predator	FW	MALE	RSTA
		In Situ Group	Laima	FW	LAE	Meteorology & research
		Lear Astronics	SkyEye	FW	MR	RSTA
		Lockheed Martin/Boeing	Darketer	FW	HALE	Recon/Surveillance
		MiTex	Backpack UAV	FW		Commercial/Recon
		NASA/Scaled Composites	Raptor	FW	HALE	Research/Offensive
		Northrop Grumman	Sea Ferret	FW	MR	Recon, Offensive
			BQM-74C Recce	HSSW	MR	Recon
		Pioneer UAV Inc.	Pioneer	FW	MR	RSTA
		SAIC	Vigilante	VTOL	MR	RSTA, comms relay
		S-Tec	Sentry	FW	SR	Recon/Surveillance
		Tledyne Ryan Aeronautical	Global Hawk	FW	HALE	Surveillance
			Scarab	HSSW	MR	Recon
		United Technolog, Sikorsky	Cypher	VTOL	SR	RSTA

Source: Peter van Blyenburgh 1999. "UAVs: Current Situation and Considerations for the Way Forward." *Development and Operation of UAVs for Military and Civil Applications*. RTO EN-9.

Note. FW=Fixed-Wing, VTOL=Vertical Take-Off and Landing, HSSW=High speed small wing, L-t-A=Lighter than Air
LADP=Low Altitude Deep Penetration, CR=Close Range, SR=Short Range, LAE=Low Alt. Endur, MR=Medium Range, HALE=High Altitude Long Endurance, MRE=Medium Range Endurance, LETH=Offensive
RSTA=Reconnaissance, Surveillance, target acquisition, EW=Electronic warfare

of UAV development in Japan, which is considered to be the root of agricultural UAVs worldwide, we will shed light on the history of pesticide spraying UAVs, which has rarely been mentioned until now. Based on the perspective of "incremental innovation" (Israel M. Kirzner 1973) and "induced innovation" (Yujiro Hayami and Vernon W. Ruttan 1971; 1985), we emphasize 1) continuity between MAVs and UAVs, and 2) prerequisites for UAV development.

First, the importance of innovation has been emphasized in research on Japanese economic and business history. In his newest book *History of Innovative Entrepreneurs in Japan*, Takeo Kikkawa (2023), as a distingguished historian, argued how the Japanese economy was able to sustain one of the highest rates of growth in world history over an extended period between the 1910s and 1980s, the most significant reason was not the destruction of equilibrium, named "creative destruction" by Schumpeter, but rather the cumulative, gradual innovation process that creates equilibrium, or "incremental innovation" named by Kirzner (Takeo Kikkawa 2023, 2). However, similar to previous research on innovation in modern and contemporary Japan, Kikkawa did not focused on the agricultural sector.

Second, the hypothesis of "induced innovation" was presented relatively early by Hayami and Ruttan from the perspective of international agriculture or development economics (Yujiro Hayami and Vernon W. Ruttan 1971; 1985) and has had an enormous influence on the field of international economic development (Alan L. Olmstead and Paul Rhode 1993; David Sunding and David Zilberman 2000). The induced innovation hypothesis argues that innovation is driven by economic conditions, particularly challenges such as resource scarcity or regulations, and it depends on the availability of technical feasibility and scientific advancements. Based on a comparison between Japan and the US before and after WWII, it would not be an exaggeration to say that "induced innovation" was a kind of "incremental innovation" that has progressed throughout a century of modern economic growth.

Hayami and Ruttan (1971; 1985) highlighted that Japan's agricultural growth was driven primarily by advancements in biological technology, particularly seed improvements that increased rice yield with increased fertilizer use despite land scarcity. Pre-WWII biological innovations significantly boosted productivity, whereas postwar growth was further enhanced by the supply of new industrial inputs, such as chemical pesticides, insecticides, garden tractors, and tillers, in response to rising farm wages due to labor shifts. Progress in fertilizer use has also led to increased pest vulnerability, prompting research on agricultural chemicals, plant physiology, and entomology. This, in turn, has fostered more fertilizer-responsive crops. Both the US and Japan showed sharp contrasts in the patterns of agricultural growth and achieved sustained agricultural productivity growth through a century of technological innovations driven by institutional advancements composed of agricultural education and research systems, particularly in biological sciences and technology. The public sector played a crucial role in ensuring balanced technological progress and in supporting private research. In both countries, private firms developed farm machinery and chemicals through public sector research and training programs, aiding this progress. In Japan, while the central government plays a strong role, the decentralization of decision-making at the prefectural level enhances responsiveness to market forces and farmers' needs, which is crucial for fostering an induced innovation process that depends on collaboration between researchers and users.

An important implication for this study is that, in the postwar development of agriculture in Japan, industrial inputs, such as chemical pesticides and insecticides, were induced and promoted with the support of various public research institutes, as the advancement of fertilizer use increased the vulnerability of agricultural crops to pests. In addition, in another of his book written in Japanese, Yujiro Hayami (1973, 101-128) analyzed examples of prewar fertilizer and postwar tractors, pointing out how progress in agricultural production goods in the non-agricultural sector improved the conditions for supplying these goods, lowered prices, promoted inputs, and contributed to improving the productivity of land and labor. He then emphasized that economic development must be seen as an evolutionary process of the division of labor between the agricultural and non-agricultural sectors. Furthermore, the case study by Toshiyuki Kako (1987), based on the "induced innovation" hypothesis, is highly suggestive for this study, emphasizing that the history of the development of the walking-type tractor (power tiller), which evolved from large to small, reflects a continuous process of adapting imported tractor technology to the changing conditions and needs of Japanese agriculture[1].

However, these studies did not fully acknowledge 1) the development of the mechanization of pesticide spraying, including UAVs, which accompanied the mass use of pesticides caused by increased fertilizer application that made rice plants susceptible to pests and insects, and 2) the nature of pest control technology, which has also been deeply related to pesticide research and pesticide spraying. This study aims to clarify the development process of pesticide spraying machinery, using aerial pesticide spraying as an example of "incremental innovation" and "induced innovation," while focusing on the interrelationship between the agricultural sector, which seeks to control pests and insects, and the non-agricultural sector, which works to develop and diffuse aerial pesticide spraying.

Hence, the main research questions addressed in this article are as follows: Why was aerial pesticide spraying important in Japanese rice cultivation? How did aerial pesticide spraying, particularly manned aviation, get started, and how has it diffused and transformed? Furthermore, as manned aerial pesticide spraying has been replaced by unmanned aviation since the 1980s, it is also crucial to investigate the weaknesses of manned aerial pesticide spraying.

1. Aerial Control in Agricultural in the post-war Japan

As shown in Appendix 1, the agricultural and forestry control focus of this study is a pesticides spraying project aimed at exterminating and preventing pests in agriculture (mainly rice) and forestry (mainly pests and diseases damage). Based on data from Appendix 1, Figure 2 highlights the following characteristics: 1) pesticide spraying, which initially began in forestry by fixed-wing aircraft (manned airplane), has primarily been conducted in agriculture by helicopters since the early 1960s; 2). The area sprayed in agriculture increased from 1,045 ha in 1958 to a postwar peak of 1.8 million ha in 1988. Although this figure has since declined, it has stabilized at approximately one million ha since the late 2000s; and 3) The

[1] Incidentally, Mitsuzo Goto (1990), Toshiyuki Hokimoto (1999) and Syunzo Teruoka (2003) clarified that by the 1970s, a unique Japanese machinery system was formed, called the "Japanese-style medium-scale integrated mechanization system for rice farming," which differed from the Western-style "large tractor + attachment + large combine harvester." The system was characterized by non-general-purpose mechanization for specific tasks and medium-scale mechanization suited to small-scale management.

type of agricultural aerial spraying can identify four periods: the period up to the mid-1950s, when manned aviation changed from fixed-wing to helicopters; the period up to the 1980s, when manned helicopters continued to increase and grow; the period from the 1990s to the present, when unmanned helicopters emerged and dominated spraying; and finally, the period from the late 2010s, marked by the rise of unmanned multicopter (drones). This study focuses on the first two periods.

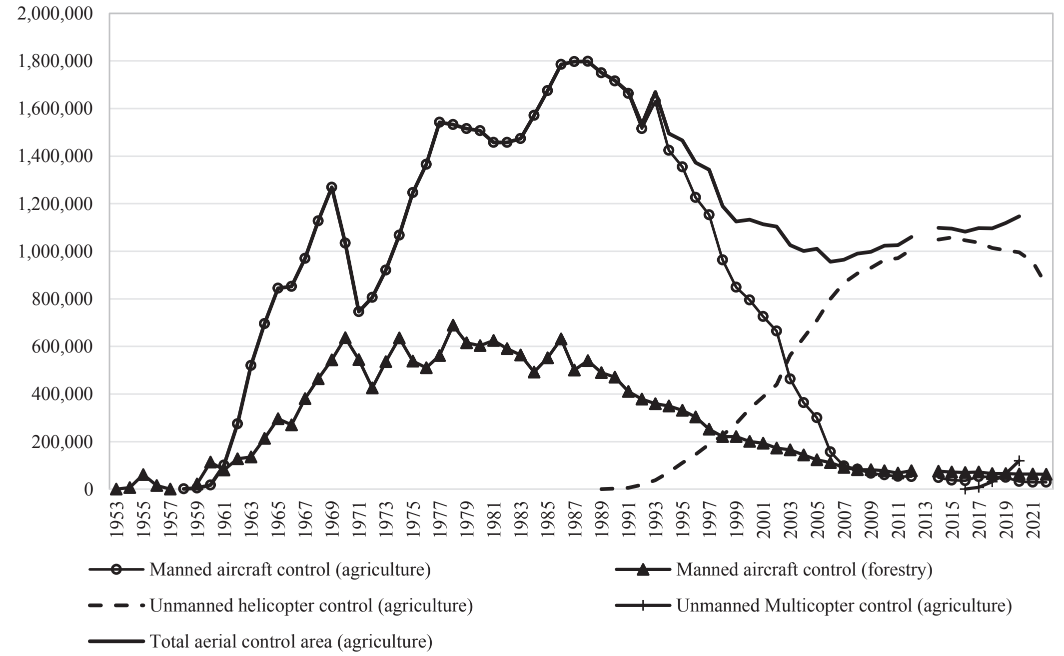

Figure 2.
Trends in the Area of Agricultural and Forestry Control by Manned and Unmanned Aircraft (ha)

Source) See Appendix 1.

Figure 3 shows the ratio of aerial control to rice planted area (total area and actual area) and highlights two points: 1) while the area planted with rice has been shrinking for a long time since the late 1960s, the aerial spraying ratio (total area) exceeded 80% in the late 1980s with the increase in manned aerial control (see Figure 2). Although it has decreased since then, it has been increasing again to the 60% range since the 2000s against the backdrop of the increase in unmanned aerial control, and 2) the aerial control ratio (actual area) is limited to the period from 1971 to 1985 due to data limitations, but it rose significantly from 17% to 29% during that period, implying that the control of approximately one-third of the total area planted with rice came to be carried out by aerial control. The aerial spraying ratio (total area) was consistenly higher than the aerial control ratio (actual area) because the total area sprayed was sprayed multiple times at the same location. For example, the average number of sprayings (total area of rice sprayed/actual area of rice protected) steadily increased from 1.5 times in 1971 to 2.0 times in 1976 and 2.4 times in 1980 (Shadan Hojin Norin Suisan Koku Kyokai 1987, 242).

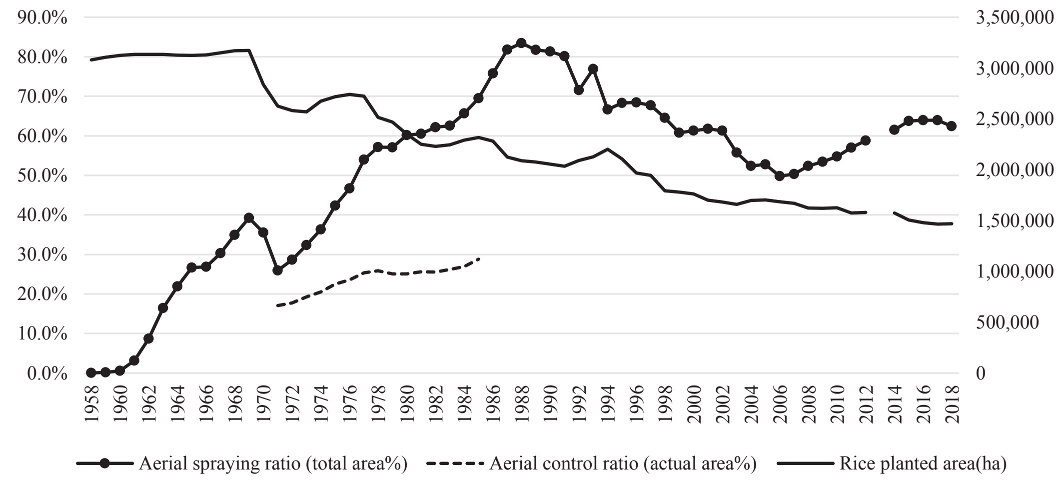

Figure 3:
Ratio of aerial control to rice planted area (total area and actual area)

Source: Aerial spraying (total area) is from Appendix 1; Aerial control (actual area) is from *Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business)*, shadan hojin norin suisan koku kyokai, 1987; Rice planted area is from "Sakuzuke chosa" (Crop Statistics Survey) Production, Distribution and Consumption Statistics Division (e-stat) of the Ministry of Agriculture, Forestry and Fisheries.

Note: Aerial control ratio (actual area) = actual area of aerial control/rice planted area, Aerial spraying ratio (total area) = total area of aerial spraying/rice planted area

However, it is essential to note that regional variations exist in aerial control (see Table 2). The actual area ratio of the aerial control of rice was high across the board in eastern Japan, which was in the top 10 for the actual aerial contral area in 1975 and 1983 (Tochigi, Ibaragi, Akita, Saitama, Nagano, Chiba, Niigata, Miyagi, Iwate in 1975; Tochigi, Ibaragi, Miyagi, Akita, Chiba, Niigata, Saitama, Iwate, Fukushima in 1983). Most of these regions maintained or even improved their high levels during the period. The proportion of farms implementing aerial control in these regions was also high[2]. For example, Niigata Prefecture increased its aerial control area, ratio of actual aerial control area, and proportion of farms that implemented aerial control from 28,647 ha, 16.7%, and 17.9% in 1975 to 45,116 ha, 29.8%, and 29% in 1983 respectively (see Table 2). In 2003, the ratio of the actual aerial control area changed dramatically to 50.8% (the actual control area, including aerial control: 116,200 ha), with 28.5% manned aircraft and 22.3% unmanned helicopters (Niigataken Shokubutsu Boeki Kyokai 2004, 6). Furthermore, as observed in

[2] As will be described later, the most important aerial control is rice blast. There are three types of rice blast: “Northern Japan type,” “Southern Japan type,” and “Intermediate type,” and the occurrence of these disease varies by region, but it is said that rice blast outbreaks are particularly prevalent in northern Japan and highland areas due to cold damage and drought, causing great damage (Izumi Kiyoichi & Ukai Kenzo 1957; Izuka Yoshihisa 1957). In light of this situation, it was emphasized relatively early in 1950s on that damage can be avoided if a pest forecasting system, such as meteorological observations are implemented during the rice growing season, can be established. As shown in Table 3, the fact that aerial control was concentrated in northern Japan is thought to have been largely influenced by the causes of blast outbreaks and differences in the forecasting system. This point remains to be a topic in the future.

Table 2 Rice control by MAVs (helicopter) by prefecture

		1975					1983				
		Actual control Area (ha)	Total control area(ha)	actual aerial control area on ratio (%)	aerial control number of farms (household)	aerial control farm on ratio (%)	Actual control Area (ha)	Total control area(ha)	actual aerial control area on ratio (%)	aerial control number of farms (household)	aerial control farm on ratio (%)
Tohoku	Aomori	1,766	3,532	2.2	1,212	1.1	6,845	12,092	9.3	3,175	3.2
	Iwate	25,557	70,133	27.7	29,152	23.7	34,926	111,764	43.3	42,745	36.7
	Miyagi	27,750	91,231	23.3	28,817	24.6	58,108	247,848	53.7	56,812	51.0
	Akita	67,574	158,819	54.2	53,306	46.0	52,716	137,522	47.4	42,390	39.1
	Yamagata	9,246	25,955	9.1	10,099	9.4	11,102	47,309	12.2	11,483	11.8
	Fukushima	19,648	32,610	18.2	17,642	11.4	33,393	85,946	34.2	34,496	24.2
Kanto	Ibaragi	71,786	114,147	67.0	128,814	67.0	63,172	104,125	65.5	103,211	60.9
	Tochigi	83,695	138,999	81.9	75,051	67.8	71,262	125,755	85.1	57,532	56.6
	Gunma	10,867	22,814	33.0	19,840	17.4	7,582	23,148	28.2	12,765	12.9
	Saitama	52,461	105,410	83.3	82,807	59.8	36,321	76,657	74.1	57,456	48.5
	Chiba	39,651	64,076	45.1	60,556	39.7	48,340	84,671	63.8	73,891	55.9
	Kanagawa	2,969	5,407	44.0	3,796	7.1	1,324	1,914	25.6	3,730	7.8
	Yamanasi	3,362	5,330	30.6	8,729	12.4	544	544	6.8	1,330	2.1
	Nagano	43,724	55,953	67.7	93,824	46.3	16,134	23,443	31.5	36,210	19.1
Hokuriku	Niigata	28,647	65,443	16.7	33,125	17.9	45,116	137,492	29.8	46,457	29.0
	Toyama	11,824	11,824	18.4	9,288	12.4	15,111	26,969	27.6	15,499	22.3
	Fukui						1,701	5,117	4.6	3,461	6.6
Tokai	Gifu	3,007	7,138	5.9	5,252	4.3	4,790	12,176	11.9	8,863	7.6
	Aichi	5,310	7,476	8.9	9,287	5.7	4,769	8,637	10.2	7,682	5.3
	Mie	7,396	14,393	12.7	12,217	10.9	7,475	17,853	15.5	10,915	11.2
Kinki	Siga	41,309	67,484	75.5	76,580	90.0	37,526	65,305	82.5	67,295	89.2
	Gyogo	2,348	2,348	3.1	4,114	2.4	410	410	0.7	710	0.4
Chugoku	Hiroshima	1,350	1,350	2.6	1,726	1.2					
Sikoku	Tokushima	762	1,055	3.4	947	1.4					
Kyuchu	Saga	6,597	6,943	13.6	4,640	6.9	350	350	0.9	246	0.4
	Kumamoto	18,191	37,359	25.3	17,846	12.9	16,052	25,863	26.9	18,924	15.9
	Miyazaki	21,585	28,463	55.9	50,484	53.7	8,780	16,828	28.8	21,020	26.2
	Kagoshima	3,204	4,556	6.7	10,525	5.1	4,687	5,177	12.2	15,141	9.3
	Total	611,586	1,150,248	22.5	849,676	16.9	588,536	1,404,915	25.9	753,441	16.7

Source: Norin sisan koku kyokai 1976 & 1983, *Norin sisan koku nianpo (Annual report of agriculture, forestry, fisheries and aviation)*.

Note: 1. Actual aerial control area on ratio = Actual control Area/ Cultivated area of rice. Aerial control farm on ratio = aerial control number of farms/Total number of farmers

2. Areas where no data existed (Tokyo,Sizuoka, Ishikawa, Kyoto, Osaka, Nara, Wakayama, Tottori, Simane, Okayama, Yamaguchi, Kagawa, Ehime, Kochi, Fuoka, Nagasaki, Oita, Okinawa) were excluded.

postwar agricultural aerial control in Miyagi Prefecture, which will later be analyzed in detail as a typical example, the actual area ratio of rice control conducted via aerial methods increased significantly, rising from 1.4% in 1962 to 13.1% in 1968, 23.3% in 1975, 36.1% in 1977, 45.1% in 1978, and reached 53.7% by 1983 (Miyagi Prefecture et al. 1982; Table 2). The remaining control was provided by ground spraying with power sprayers and dusters (Table 3).

Table 3 ownership of power sprayers and dusters

	Number of machines owned (individual and shared, 1000)		Percentage of farmers using them (%)
	power sprayers	power dusters	
1935	0.6		
1939	5		
1945			
1950	16		
1955	53	8	
1960	232	73	35.8
1965	494	206	
1970	961	1,215	58.7
1975	1,316	1,291	61.9
1980	2,140		55.2
1985	2,151		53.2

Source: Mitsuzo Goto 1990. "Sengo Nogyo Gijutus no Tenkai to Nogyo Kozo no Henka (Postwar development of agricultural technology and changes in agricultural structure)." *Social history of technology*, Yuhikaku, 31.

2. Pesticide in the Aerial Control

Problems such as the acute toxicity of pesticides, contamination of crops, soil, and water systems by pesticides, and adverse effects on wildlife have been attracting worldwide attention since the late 1960s; however, the importance of pest control (crop protection) based on pesticides spraying has not decreased, and in fact, is increasing along with global population growth (Oerke et al. 1994; Oerke 2006). The precise spraying of pesticides using MAVs and UAVs since the 1970s can be considered a typical technological innovation.

Oerke et al. (1994) emphasized that 1) rice losses in the world due to diseases, animal pests, and weeds were estimated at 82% without protection or control, compared to an actual loss rate of 51% during 1988-1990; 2) as a consequence, the average EF (efficacy of actual rice protection practices) was estimated at 37.8%; and 3) Japan (73.3%), Australia (61.0%), North America (57.1%), and Western Europe (53.3%) were among the countries showing the highest levels with the effective means of crop protection (pest control) (see Table 4). In fact, as Oerke et al. suggested, in Japan and the US, the relative expenditure on pesticide increased from 29.4% and 27.1% during 1968–1970 and 1969–1971, respectively, to 43.5% in both countries during 1986–1988 and 1985–1987 (Oerke et al. 1994, 38).

The production (shipment) volume of pesticides rose from less than 50,000 tons in the early 1950s to over 700,000 tons in 1974 but then dropped sharply (see Figure 4). Looking at the composition of formulations, dust, which had been driving pesticide production after the war, peaked in the late 1960s and then declined. In contrast, granules grew rapidly, and even as pesticide production declined, showed a steady trend from the late 1970s to the mid-1990s, continuing to occupy a major position in pesticide production. The decline in pesticide production since the early 1970s may have been due to a decrease in

Table 4 Region/Country differences in the efficacy of actual rice protection practices in 1988-90

Region/Country			Potential loss rate (A,%)	Actual loss rate (B,%)	EF (%)
Africa	(overall)		82	54	34.1
America	(overall)		85	50	41.2
	North America		84	36	57.1
	Central America		85	55	35.3
	South America		85	54	36.5
Asia	(overall)		82	51	37.8
	Near East		83	55	33.7
	South Asia		84	60	28.6
	South East Asia		81	54	33.3
	East Asia (overall)		82	40	51.2
		China	82	42	48.8
		Japan	86	23	73.3
		Korea Rep.	77	27	64.9
		Taiwan	82	40	51.2
Europe	(overall)		75	36	52.0
	East Europe		73	42	42.5
	West Europe		75	35	53.3
U.S.S.R			70	42	40.0
Oceania	(overall)		60	24	60.0
	Australia		59	23	61.0
	Fiji, etc.		72	46	36.1
World	overall		82	51	37.8

Source: Oerke,E.-C., Dehne, H.-W., Schonbeck, F. & Weber, A. 1994. Crop Production and *Crop Protection - Estimated Losses in Major Food and Cash Crops*. Amsterdam: Elsevier Science, 160-161.

Note: EF=(A-B)/A

pesticide demand accompanying a decrease in the area of rice paddy cultivation, but the most crucial factor was that, against the backdrop of strengthened pesticide regulations, as typified by the major revision of the Agricultural Chemicals Regulation Act in 1971, the amount of pesticide sprayed per unit area has decreased due to 1) improvements in pesticide performance and formulations to reduce the amount of pesticide used and its toxicity, and 2) advances in pesticide spraying technology, which is considered to be inseparably linked to pesticide development (Hiroki Ota 2015, 47; Sasaki et al. 2003, 60-65; Shoici Matusnaka 2002, 15-21; Kouzo Tsuji 1998, 1).

The rough index of the amount of pesticide sprayed per hectare of rice paddy also peaked in 1974 and then declined, which aligns with the trend in pesticide production (see Figure 4). Furthermore, when limited to aerial spraying, the amount of pesticide used per hectare in agriculture has increased since the 1960s, but has been decreasing for a long time, peaking at 23.5 kg in 1970. Incidentally, the level in 1993 was only 2.7 kg, which was approximately 10% of the 1970 level (see Table 5). In addition, as can be seen in Figure 4, which shows the area of application of pesticides by type of spraying formulation from 1970 to 1985, when agricultural spraying by manned aircraft (helicopters) rapidly increased, dust formulation,

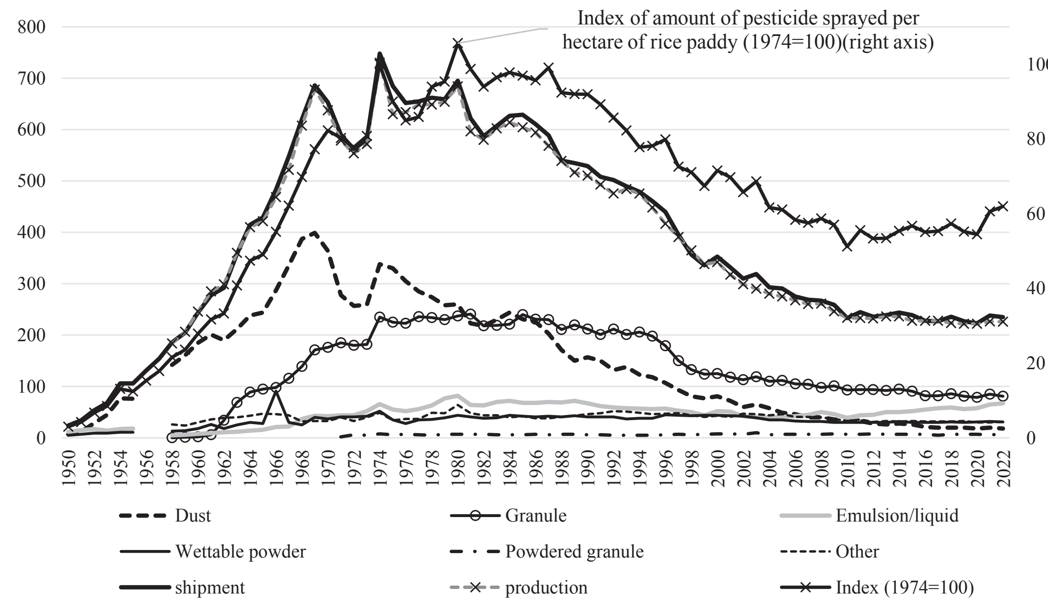

Figure 4

Postwar production volume of pesticide by formulation (thousand tons)

Source) *Noyaku yoran (Pesticide Handbook)* (various editions). Nihon noyaku gakkai 2003. *Nihon no noyaku kaihatu (Pesticides Development in Japan)*, 60. "Sakumotu tokei: shukakuryo ruinian tokei (Crop statistics: Annual harvest statistics)" (e-stat).

Note: Shipment volume = production volume + import volume - export volume.

Table 5 Amount of aerial spraying pesticides used per hectare in agriculture

	Aerial control area (ha)	Amount of pesticides shipped for aerial spraying (kg)	Amount of pesticides used per hectare (kg)
	A	B	B/A
1964	695,452	13,145,813	18.9
1970	1,034,582	24,318,026	23.5
1975	1,245,935	16,403,900	13.2
1980	1,506,916	11,352,877	7.5
1985	1,675,419	7,195,833	4.3
1990	1,718,131	5,604,941	3.3
1993	1,669,496	4,552,674	2.7

Source: *Norin suisan koku nenpo (Agricultural, Forestry and Fisheries Aviation Annual Report)*, Norin suisan kouku; Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business), shadan hojin norin suisan koku kyokai, 1987; *Norin suisan koku jigyo 50-shunen kinen-shi (Agricultural, Forestry and Fisheries Aviation Business 50th Anniversary Book)*, shadan hojin norin suisan koku kyokai, 2013.

which was prominent in 1970, rapidly decreased after that, whereas ultra-low volume (ULV) sprays, liquids, and liquids (low volume) rapidly grew to become the central players in spraying from the mid-1970s onwards (see Figure 5).

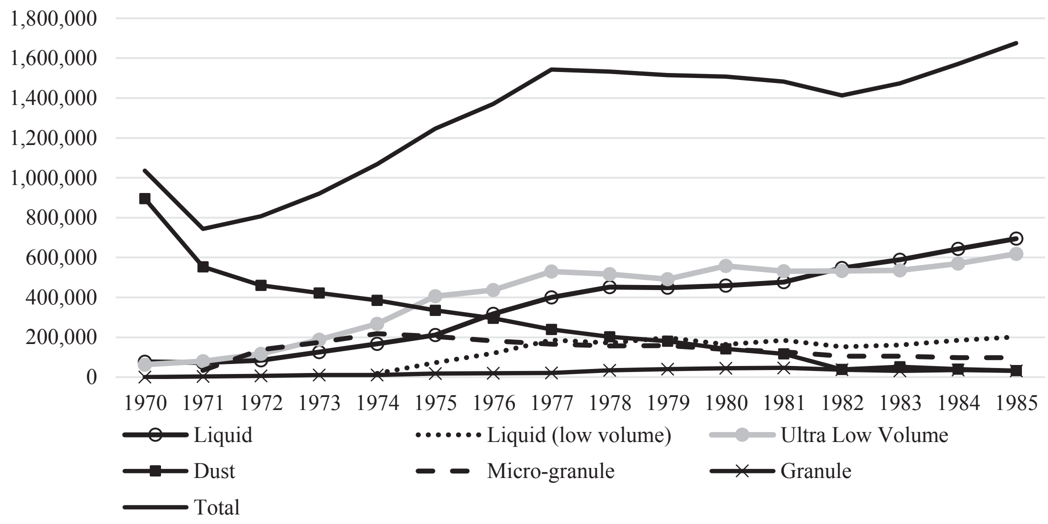

Figure 5

Areas sprayed by manned aircraft (helicopters) by type of pesticide (ha)

Source: *Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business)*, shadan hojin norin suisan koku kyokai, 1987.

A similar trend is observed in the ownership of spraying apparatus kits, which were attached to helicopters, depending on the type of pesticide used for aerial spraying (see Figure 6). The apparatus kits are owned by commercial air services companies, such as Fuji Aircraft, Asahi Helicopter, ANA, and Nihon Norin Hekicopter (see below), and approved by the Japan Agricultural Aviation Association (JAAA) under the Ministry of Agriculture and Forestry (MAF; now the Ministry of Agriculture, Forestry and Fisheries (MAFF)) before their use, as well as the pesticides mentioned above (Hatai Naoki 1968). The number of apparatus kits has increased steadily since the 1950s compared with the number of helicopters in operation. Consequently, the number of kits per helicopter in operation rose by 3.5 times between the 1950s and the 1980s. Prior to 1970, dusters (for dust application) were the predominant form of pesticide application. However, since the late 1970s, dusters have been progressively replaced by sprayers (for liquid application), granule applicators, ultra-low volume (ULV) systems, and microgranule applicators.

3. Japan’s Plant Protection System and the Establishment of Japan Agricultural Aviation Association

3-1. Japan’s Plant Protection System

As mentioned above, among four periods, the first period extended up to the early 1950s, when manned fixed-wing airplanes dominated. However, between the mid-1950s, there was a significant transformation from fixed-wing to helicopters. Hence, the main research questions addressed in this chapter are as follows: How do fixed-wing airplanes embark? Why did the transformation occur? What kinds of players have been

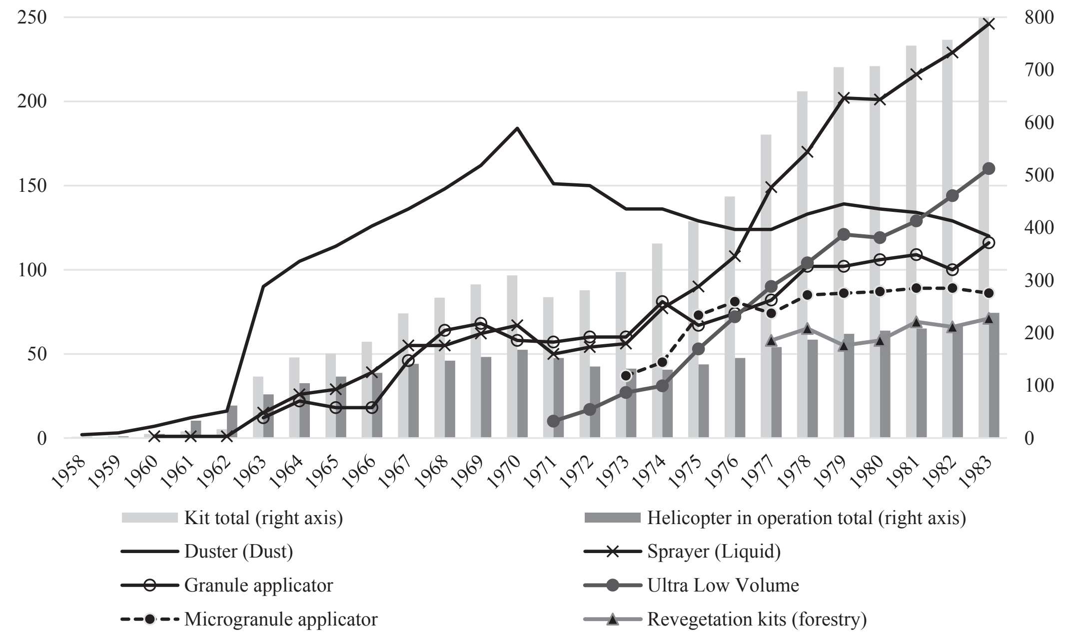

Figure 6

Aerial (helicopter) pesticides spraying apparatuses ownership record (set)

Source: *Norin suisan koku nenpo (Agricultural, Forestry and Fisheries Aviation Annual Report)*, Norin Suisan kouku; *Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business)*, shadan hojin norin suisan koku kyokai, 1987.

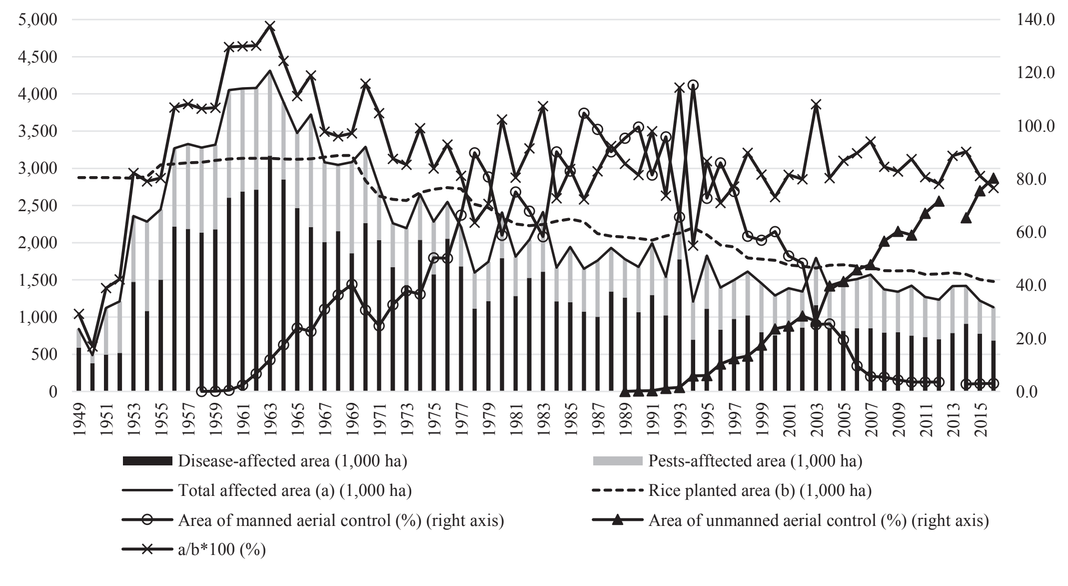

Figure 7

Diseases & pests affected rice area and aerial control status

Source: Appendix 1; Rice planted area is from "Sakuzuke chosa" (Crop Statistics Survey) Production, Distribution and Consumption Statistics Division (e-stat) of the Ministry of Agriculture, Forestry and Fisheries.

fulfilling the roles in the beginning of the increasing spraying?

First, although the total affected area of rice planted with diseases and pests has been on a downward trend postwar, in line with the decrease in the rice-planted area, the proportion of the area affected by diseases and pests in the rice-planted area has remained consistently high (see Figure 7). Under these circumstances, manned and unmanned aerial spraying is expected to play a major role in the long-term control of diseases and pests. The principal diseases and insect pests of rice in Japan are Panicle blast (pathogen: Pyricularia oryzae), Bakanae disease (Gibberella fujikuroi), Seedling blight (Pythium, Rhizoctonia, etc.), Sheath blight (Rhizoctonia solani), Leaf blast (Pyricularia oryzae), Dwarf virus, Stripe virus, White-backed planthopper, Smaller brown planthopper, Green leafhopper, Stem borer, Stink bug , among otheres (Oerke et al. 1994, 148-151). As mentioned above (see Table 4), Japan had the highest levels of effective means of plant protection and relative expenditure on pesticides among the developed countries. Such world-class standards of plant protection in Japan would be difficult to comprehend without considering the plant protection system promoted and established throughout the country by the plant protection administration, which focuses on tasks such as disease, insect control, and forecasting (see Figure 8).

The characteristics of Japan's plant protection system can be described as follows (Nihon Shokubutsu Boeki Kyokai 1971; Nihon Shokubutsu Boeki Kyokai 1980; Nihon Shokubutsu Boeki Kyokai 2020). First, the Plant Protection Division, established in 1951 under the Plant Protection Act of 1950, is at the top of the plant protection administration. This law was enacted to address pest control, which was critical for postwar efforts to boost food production.[3] The division's main duties include planning pest control strategies, providing guidance, forecasting pest outbreaks, and overseeing the production, distribution, inspection, and regulation of pesticides. The division's policies are supported by pest and pesticide research conducted by various testing and research institutions, including the agricultural experiment stations with which it maintains close ties. At the same time, each prefecture has its own plant protection department that works not only in cooperation with the national plant protection plan but also in developing, guiding, and implementing plant protection measures within the prefecture. These departments collaborate closely with prefectural testing stations and plant protection councils. The councils comprise a range of agricultural organizations, such as Agricultural Committees, Zenkyoren (National Mutual Insurance Federation of Agricultural Cooperatives), Agricultural Production Cooperative Federations, Purchasing Industrial Cooperative Federations, Pesticide Cooperatives, and Agricultural Machinery

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[3] Incidentally, plant protection had already begun in Japan in the prewar period. Regulations and laws such as Rice Field Insect Prevention Regulations (1885), Pest Prevention and Control Act (1896), Regulations for Promoting the Prevention and Control of Disease and Pests (1911), and Import and Export Plant Quarantine Act (1914) were established. Simultaneously, research and testing were enhanced by the MAF's Agricultural Experiment Station, universities, prefectural agricultural experiment stations, and nationally commissioned testing. Furthermore, in 1941, a system of disease and pest outbreak forecasting was started in response to the large-scale outbreak of rice blast and planthoppers the previous year. However, since the unified and systematic control system for disease and pests both overseas and domestically was deemed weak overall, the Import and Export Plant Quarantine Act (1914) and the Pest Prevention and Control Act (1896) were consolidated in 1950 to form the Plant Protection Act. This was a turning point for Japan's plant protection system (Nihon Shokubutsu Boeki Kyokai 1971, 3-5; Rin Iwakiri 1965, 3-6). Researching the development of plant protection efforts in the prewar period will present a future challenge.

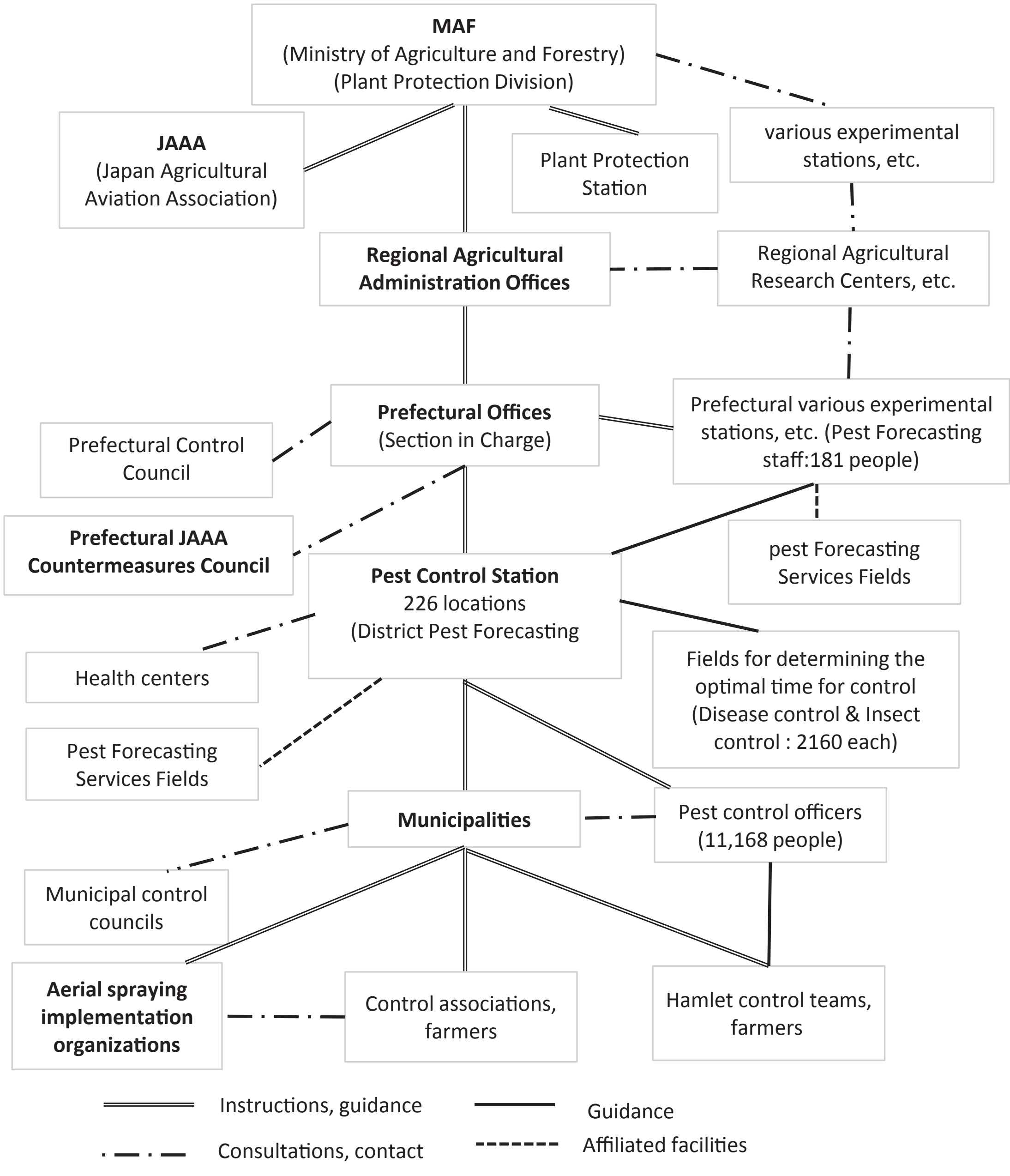

Figure 8

Plant Protection Organization Chart in 1980

Source: Nihon Shokubutsu Boeki Kyokai 1971. *Shokubutsu boeki nijunian si (20th Anniversary of Plant Protection Project), 40*; Japan Plant Protection Association 1980. *Shokubutsu boeki sanjunian no ayumi (Thirty Years of Plant Protection)*, 22; Japan Plant Protection Association 2020. *Noyaku gaisetsu 2020 (Pesticides Overview 2020)*, 17.

Cooperatives, ensuring a coordinated approach to plant protection.

Second, Pest Control Stations, established in 1951 with approval from the MAF, are local prefectural agencies that handle the practical aspects of plant protection at the prefectural and municipal levels. Their responsibilities include planning pest control activities, guiding municipalities and agricultural organizations, forecasting pest outbreaks, and managing the storage and repair of pest control chemicals and equipment. By 1980, over 10,000 pest control personnel, approved by the Minister were employed at 226 pest control stations across the country, with 54% from JA (Japan Agricultural Cooperatives), 15% from Nosai (National Agricultural Insurance Association), 9% from municipal offices, and 22% from farmers and others. These personnel played crucial roles in drafting control plans, monitoring pest and disease outbreaks, and ensuring the safe use of pesticides. Furthermore, by 1970, municipal pest control councils were established in approximately 80% of municipalities, serving as primary organizers of pest control activities. These councils, composed of municipalities, Nosai, JA, and pest control teams, played a major role in promoting pest control. While hamlet pest control teams were originally created for joint pest control efforts, their numbers declined from 184,768 in 1964 to approximately 90,000 by the 1970s (Nihon Shokubutsu Boeki Kyokai 1971, 42; Nihon Shokubutsu Boeki Kyokai 1980, 42). This decrease was driven by several factors, including the reduction in full-time farmers and the rise in part-time farmers due to the outflow of agricultural labor to cities, a reduction in village agricultural promotion leaders, the availability of smaller, lighter, and cheaper pest control equipment, and a shift from highly toxic pesticides to low-toxicity alternatives. In response, the establishment of pest control associations in the municipalities of Nosai and JA has been promoted. By 1976, Nosai-based pest control associations accounted for the largest share (35%) of the 1,848 municipalities engaged in joint rice pest control (Nihon Shokubutsu Boeki Kyokai 1980, 40).

Third, the JAAA, which is also featured in the organizational chart (Figure 8) and is the focus of this study, has also played a crucial role as the promoter of aerial control in the plant protection system under the guidance and instructions of the MAF. The details of its establishment and role will be described later, but the JAAA was established in 1962 under the leadership of the MAF as an external organization with the aim of promoting and developing the business of using aircraft in the agriculture, forestry and fisheries industries. It is no exaggeration to say that its establishment was a bottom-up organization born out of the voluntary activities of local experimental stations in the plant protection system. The JAAA considers the number of aircraft that airlines can supply and the appropriateness of fees for the business plans of the prefectures presented by the MAF, creates a national implementation plan (operation flight schedule), and obtains approval from the MAF. In addition, the Prefectural JAAA Countermeasures Council was used to make various adjustments at the prefectural level.

3-2. JAAA's Establishment

The founding members in 1962 were the following six organizations (Japan Plant Protection Association, Nosai, Agricultural Chemicals Industry Association, JA-Zenchu [Central Union of Agricultural Cooperatives], National Federation of Agricultural Purchasing Cooperative Associations, National Federation of Agricultural Chemicals Commercial Cooperative Associations) and 17 companies (Kawasaki Aircraft Industry, Asahi Helicopter, Nippon Agricultural Helicopter, Fuji Aviation, All Nippon Airways, Imperial Airways, Nippon Domestic Airlines, Keisei Electric Railway, Mitsuya Airlines, East Japan Airlines, Nakanihon Air Service, Nitto Airlines, Hankyu Airlines, Osaka Airways, Kanki Airlines, Setouchi Airlines, Nishinippon Airlines) (Shadan Hojin Norin Suisan Koku Kyokai 1987, 12-13). The main background to the establishment was that 1) in 1953, owing to the urgency of pest control, agricultural experiment stations in Hokkaido, Ishikawa, and other prefectures tried aerial spraying, which was popular overseas, one after another, and obtained good results, leading to a tight supply and demand for aerial spraying, and 2) the outflow of the agricultural labor force from the mid-1950s had become noticeable, among other reasons.

The first use of aircraft in agriculture, forestry and fisheries in Japan occurred in 1923 when the Mie Prefectural Fisheries Experiment Station used a fixed-wing seaplane to report fish schools in coastal fisheries (Nihon Shokubutsu Boeki Kyokai 1971). The first aerial pesticide spraying was an experimental and practical spraying carried out in Hokkaido from July to September 1953 under an industry-academia collaboration between the Hokkaido Agricultural Experiment Station and North Japan Airlines (which merged Nitto Airlines and Fuji Airways in 1964 to become Japan Domestic Airlines) (Satoru Kuwayama 1954; Kuwayama et al. 1954; Hidetsugu Ishikura 1962). Specifically, North Japan Airlines, established in June 1953, sought guidance and advice from Kuwayama Satoru of the Hokkaido Agricultural Experiment Station when it was commercializing agricultural and forestry pest control as part of its business expansion. Kuwayama visited the US in 1951 and sensed the potential for aerial pest control at a relatively early stage, in which Japan had lagged, and decided to cooperate[4]. Under the guidance of Kuwayama, North Japan Airlines, with the dusting apparatus they had designed and developed themselves, installed it on a small fixed-wing Cessna 170 C-type aircraft and conducted several tests on controlling agricultural and forestry pests at the Okadama Aerodrome near Sapporo on July 21. On July 24 and August 12, they sprayed BHC dust and Bordeaux dust to control gypsy-moth in the forests and farmland in Kamiokoppe village, Kitamimonbetsu province, and rice-blast disease in Takasu, Ishikari province, respectively.

In July of the same year, the Ishikawa Prefecture Agricultural Experiment Station conducted two tests in Komatsu to spray dust and control rice blight using a helicopter owned by Hokuriku Air Transport (Shigekiti Ikeya and Minoru Tamura 1953). Although rice blight broke out in Ishikawa Prefecture in 1952 and 1953, ground spraying was difficult because of prolonged rainfall; therefore, they were looking for a way to spray quickly in a short amount of time during the few sunny days. Because the results of all the spraying were good, large-scale practical use was mainly implemented for forestry pest control using a fixed-wing aircraft (see Appendix 1).

The first practical use of helicopters for rice pest control was in August 1958, when the Nippon helicopter (now All Nippon Airways) sprayed dust to control rice blasts on 1,045 ha of rice paddies in the Isehara Hiratsuka area under the guidance of Engineer Ninomiya Yuu of the Kanagawa Prefecture Agricultural Experiment Station, who pleaded with the MAF for aerial pest control during the war (Yuu Ninomiya 1958; Hidetsugu Ishikura 1962; Yuu Ninomiya 1966). It was because Isehara was an area where rice blast disease was prevalent, and the head of Isehara Town's Ota JA requested a solution due to the difficulty of spraying at the right time due to the shortage of agricultural labor force (Yuu Ninomiya 1966). This aerial control by helicopter was introduced nationwide on television news and aligned with the policy of agricultural modernization and labor shortage in rural areas, playing an educational role throughout the country (Hidetsugu Ishikura 1962). Consequently, the area (number of prefectures) where helicopter aerial

[4] The use of helicopters in aerial spraying in the US was less than 1% of the approximately 5,000 aircraft, partly because fixed-wing aircraft were available in large numbers at low cost after being sold off by the military, but also because the manufacturing and operating costs of helicopters were high (Kenji Takemoto 1962, 8).

spraying was carried out to control rice diseases and insects increased dramatically from 1,045 ha in 1958 to 272,895 ha in 1962 when the JAAA was established (see Table 6). In particular, the areas planned for spraying in 1962 covered 43 prefectures from 22 prefectures in 1961, but also nearly matched the number of areas where spraying was carried out.

Table 6 Control of diseases and insect pests by year by Hericopters (ha)

	Rice blast		Rice leafhoppers		Rice stem borer		others		Total	
1958	1,045	(1)							1,045	(1)
1959	4,041	(3)			203	(1)			4,244	(4)
1960	13,427	(10)	2,733	(2)	1,755	(3)			17,915	(13)
1961	51,881	(17)	41,918	(4)	5,510	(5)			99,309	(22)
1962	149,287	(28)	89,406	(18)	33,437	(21)	765	(2)	272,895	(42)
(planned)	(141,115)	(27)	(61,870)	(7)	(51,290)	(24)	(26,650)	N/A	(280,925)	(43)

Source: Ishikura Hidetsugu "Kuchu sanpu no kako, genjo oyobi shorai (Aerial spraying: past, present and future)." Shokubutsu Boeki (Pest Protection), 16(3), 1962, 2; Hatai Naoki "Utilization of Helicopter for Plant Protection." Japan Agricultural Research Quarterly, 3 (1), 1968, 16; Nourin suisankoku kyokai, Nourin suisan koku nianpo (Agriculture, Forestry and Fisheries Aviation Annual Report: 1953-64), 1965, 31.

Note: ( )=the number of prefectures.

The key factors behind the strong potential demand in the early 1960s were 1) an urgent need to address widespread rice diseases; 2) a report published in December 1959 by the Japan Plant Protection Association (JPPA) based on research conducted from 1954 to 1956 by Professor Hidefumi Asayama of the Faculty of Agriculture at the University of Tokyo, which aimed to verify the effectiveness of airplanes and helicopters in controlling rice pests in Japan (Nihon Shokubutsu Boeki Kyokai 1959), and 3) the Aerial Spraying Committee of JPPA, established in 1960, which briefly served as a conduit leading to the launch of the JAAA.

First, although the mechanization of ground control for rice paddies repidly progressed in the 1950s (see Table 3), there were still limitations in controlling the increasing incidence of rice blast disease. In particular, when the rice is overgrown, or ears appear, it is extremely difficult to enter a paddy field for spraying, and ground-based collective control is unable to keep up with the damage, resulting in enormous damage (Nihon Shokubutsu Boeki Kyokai 1959, 1; Shadan Hojin Norin Suisan Koku Kyokai 1987, 196). There are also cases of infections spreading from neighboring fields that are not controlled, and the effectiveness of individual control is often reduced. Aerial spraying was attracting attention as an effective collective control method for spraying pesticides over a wide area in a short time with a small number of people (Norinsho Shinkokyoku 1961, 48). A report published by the JPPA mentioned above conclusively demonstrated its effectiveness and spread it nationwide.

Second, this research examines the main requirements for aircraft used in aerial spraying of rice pest control in Japan, including short runway distances for takeoff and landing, large pesticide load capacity, stable maneuverability at low speeds, ability to climb quickly, wide visibility, small turning radius, stability in sharp turns, ability to fly and spray with a single pilot, ability to utilize downward air currents, good dust protection for each part of the aircraft, and a good harmony between the spraying equipment and the aircraft. The results clarified that 1) Cessna 170 and 195 were inappropriate in terms of their performance in light of the locational conditions of Japanese agriculture; 2) the Bell 47D1 and 47G helicopters had gained a great deal of knowledge and were fully practical; and 3) there was a need for research into improving spraying equipment and the practical application of dust and liquids for small-volume spraying. Such strong potential demand in the early 1960s was a strong driving force behind the establishment of the JAAA.

Third, the Aerial Spraying Committee of JPPA was established in April 1960, but its parent organization was the "Study Group on Spraying Pesticides by Aircraft," which was inspired by a direct result of the series of research results in the above-mentioned report and established in April 1959 (Nihon Shokubutsu Boeki Kyokai 1978; Nihon Shokubutsu Boeki Kyokai 1984, 55-57). As the momentum for the establishment of the JAAA increase, the committee "acted as a naive, groping conduit" until January 1962, when it ceased its activities (Nihon Shokubutsu Boeki Kyokai 1984, 55). The eight members of the committee consisted of three from the MAF's National Institute of Agricultural Sciences (Goto Kazuo, Hatai Naoki, Suzuki Terumaro), three from the MAF's Plant Protection Division (Sino Hidezo, Inoue Kanji, Endo Takeo), two from ANA (Yokoyama Hajime), and Asahi Hericopter (Tanba Masayuki), of which three from the NIAS and one from ANA were also members of the joint research project mentioned above[5]. This suggests that not only was there a close relationship between the establishment of the committee and the research project, but also that the members of the joint research project were, in fact, the driving force behind the committee.

Since 1960, during the eradication of rice blast disease, supply and demand have become so tight that fear control work may not be carried out in time. In response, the MAF requested project plans from the relevant prefectures and compiled requests from the implementing prefectures and airlines. It tasked them with the Aerial Spraying Committee by adjusting and creating a control implementation plan, which was then communicated to the relevant prefectures and airlines (Nihon Shokubutsu Boeki Kyokai 1980, 55-56; Shadan Hojin Norin Suisan Koku Kyokai 1987, 13). However, even in 1961, as planned regions and areas expanded rapidly and conflicts of interest between the parties involved surfaced, the implementation of the committee encountered challenges and reached its limits. After much trial and error on the part of both the JPPA's committee and the MAF, the JAAA was established as an association organization in February 1962 under the leadership of the MAF, with the JPPA, airlines and others as members[6].

Hence, the main question focused here is: Where do the conflicts of interest lie among the parties involved? The presumption that the MAF promoted the establishment of the JAAA was the nationwide cooperative use business concept of "one farm, one company."[7] This was primarily intended to solve

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5 References include Nihon Shokubutsu Boeki Kyokai (1959, 1), Nihon Shokubutsu Boeki Kyokai (1984, 55), and Various issues of Shokubutsu Boeiki (Plant protection) for 1962.

6 Initially, the MAF envisioned the establishment of a special corporation or public corporation, the Agriculture, Forestry and Fisheries Aviation Agency funded by the government and local governments. However, since the project was still in its infancy, the MAF determined that a voluntary association of private sector stakeholders would be more suitable legally, ultimately opting for an association format instead (Shadan Hojin Norin Suisan Koku Kyokai 1987, 11).

7 This section of the description is based mainly on the records of a "roundtable discussion" held by the JAAA as part of the commemorative events for the 25th anniversary of the association's establishment (Shadan Hojin Norin Suisan Koku Kyokai 1987,185-216).

various problems inherent in aerial spraying, such as regional disparities in usage fees owing to the uneven geographical distribution of aircraft, the imbalance in cost burden between the agricultural and aviation sides, and, especially, the variation in supply services between aircraft companies.

For example, since airline aircraft were unevenly distributed in metropolitan areas such as Tokyo, Nagoya, Osaka, and Fukuoka, there were concerns about who would bear the high air transport costs to remote areas outside and inside the prefecture, and how to adjust the imbalance between regions (Shadan Hojin Norin Suisan Koku Kyokai 1987, 185-216). In addition, because the implementation towns and villages had contracts with airlines, there was a disparity in spraying fees between towns and villages, even within the same prefecture, ranging from 87 to 210 yen per 10 ares. At times, during the era of the JPPA's spraying committee, there were many complaints from prefectures and airlines that the plans and costs were arbitrarily changed in response to the various adjustments made by the MAF. Furthermore, because aerial spraying is highly seasonal, aircraft tend to be in short supply. In the case of rice paddy, the spraying is extremely concentrated in a limited period of two months around August, so airlines faced a major hurdle in maintaining or increasing aircraft ownership throughout the year with profitability. There was hope for the development of a variety of uses that would allow for an average year-round operation and for airlines to voluntarily increase the number of aircraft accordingly.

To solve the above problems, the MAF implemented by announcing "Guidelines for Promoting Agriculture, Forestry and Fisheries Aviation Business"[8] along with the establishment of the JAAA, 1) the same work and same fee by the Work Fee Committee, 2) certification of pilots by the Technical Certification Committee, 3) certification of the model and performance of the spraying apparatus by the Performance Certification Committee, and 4) enhancement of the government budget to reduce various imbalanced cost burdens, improve technology, and improve aircraft shortages.

4. The development of JAAA and MAVs

The organizational role of the JAAA is shown in more detail below, based on Naoki Hatai (1968) and Figure 8. Helicopters were registered at the JAAA and kept under its control. Farmers who wish to use helicopters for plant protection work by implementing organizations submit their requests to the prefectural government through their town or village offices. Each prefectural government then submits these requests to the MAF, which directs the JAAA to prepare a year-round flight schedule covering the entire country based on helicopter availability. Once this schedule is ready and approved by the ministry, it is sent to implementing organizations through an executive committee organized under the prefectural government. Additionally, the schedule is provided to aircraft companies, which then coordinate directly with relevant organizations. As mentioned above (Figure 8), the JAAA played an important role as the promoter of aerial control between the implementing organizations and the MAF. At the very bottom of the organization, an

[8] The Guidelines stipulate the development of new fields, improvements in utilization technologies, coordination of aircraft usage, training in relevant technologies, the formation of the Agricultural, Forestry, and Fishery Aviation Business Study Group, the establishment of a promotion system, and the provision of national subsidies, all of which were communicated to prefectural governors and the JAAA (Shadan Hojin Norin Suisan Koku Kyokai 1987,13).

Table 7 Government budget for JAAA by expenditure (unit: 1,000 yen)

Year	Total	Technical training	Skill improvement project	Pilot training	Pilot traning loan project	Helecopter work adjustment implementation management	Operation comprehensive countermeasures project	Long-distance air transport	Helicopter operation (purchase subsidy)	Technology rationalization test project	New technology test and development	Technology R&D facility improvement project	International Agricultural Aviation Center share
1962	7,500	567						6,933					
1963	33,667	8,023				1,644		20,000			4,000		
1964	78,321	18,991		19,863		1,967		30,000			7,500		
1965	140,287	17,518		19,710		1,873		30,000	63,434		7,500		252
1966	90,224	17,308		19,669		1,885		33,000	10,610		7,500		252
1967	99,776	17,311		16,024		1,897		35,000	21,792		7,500		252
1968	103,154	16,102		15,651		1,775		34,410	22,701		12,263		252
1969	99,124	16,106		15,651		1,791		33,180	19,416		12,728		252
1970	99,425	16,120		18,820		1,846		32,815	16,792		12,780		252
1971	100,499	16,128		16,957		1,873		32,292	20,043		12,954		252
1972	109,748	16,138		16,957		2,058		31,632			19,147	23,574	252
1973	117,722	16,166	5,211	10,348	8,100	2,309		31,361			20,025	23,950	252
1974	123,824	14,954	3,602		19,780	3,300		28,416	20,694		11,409	21,417	252
1975	125,533	14,971	3,932		22,781	3,392	38,224		30,711		11,270		252
1976	123,846	12,773	3,371		25,525	3,878	34,739		27,074	16,486			
1977	138,179	11,787	3,245		26,539	3,618	34,178		37,962	20,850			
1978	133,716	11,792	3,265		11,592	1,706	39,095		47,617	17,516			
1979	139,461	11,792	3,300		11,202	1,677	43,389		43,665	24,434			
1980	126,220	8,046	3,300		9,452	1,543	43,596		24,823	35,460			
1981	125,657	8,046	2,750		8,999	1,543	43,596		22,194	37,809			
1982	114,823	8,046	2,750		8,996	1,543	43,596		12,083	37,809			
1983	108,293	7,644	2,612		9,236	1,466	41,416			45,919			
1984	103,103	7,262	2,481		8,999	1,392	39,346			43,623			
1985	98,279	6,899	2,233		9,103	1,322	37,379			41,343			

Source: Shadan hojin norin suisan koku kyokai, *Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business)*, 1987, 257-259.
Note: Each fiscal year runs from April of the previous year to March of the current year. 1962: February to March 1962.

important role was played by the implementing organizations, mainly JA or NOSAI in the municipalities, which planned the annual schedule together with the municipalities while considering the needs of farmers. The implementing organizations would then enter into a contract with the airlines based on that plan[9].

The government budget for the JAAA shows how active JAAA's business activities have been (see Table 7). The government budget, which was 7.5 million yen in 1962 (February to March), when the JAAA was established, has constantly been increasing, except for 1965 (April 1964 to March 1965), when subsidies for helicopter purchases exceeding 100 million yen at the end of the 1960s and reached 140 million yen at the end of the 1970s. The largest budget allocations at JAAA were 1) long-distance air transport expenditure (changed to the operation comprehensive countermeasures project in 1975) to reduce the burden of air transport costs, 2) helicopter operation expenditure including helicopter purchase to improve the shortage of helicopters, 3) technical training and pilot training expenditure (changed the previous subsidy-based training system to a crew training loan project system in 1973) to improve agricultural and forestry aviation-related technology and to improve the shortage of helicopters, and 4) R&D of new technologies for technology improvement (Shadan Hojin Norin Suisan Koku Kyokai 1987, 270-283).

First, the calculation of the long-distance air transport cost subsidy was based on the "Calculation Guidelines for Long-Distance Travel Distances" established by the MAF. In other words, the cost of long-distance air transport over 150 km from the seven bases in Sendai, Tokyo, Nagoya, Osaka, Takamatsu, Fukuoka, and Kagoshima was eligible for subsidies. 150 km was the distance where the cost of ground spraying and the cost of helicopter spraying were the same. In fact, the total distance traveled by 570 aircraft from all bases in 1963 (Aril 1962 to March 1963) was 107,563 km, of which 43,860 were longer than 150 km. The subsidy was 18,920,000 yen (430 yen per km), which is almost the same as that in Table 7 (Tekeo Endo and Yuu Naito 1963, 103)[10]. Additionlly, aerial spraying had already been evaluated as having almost the same economic effect (cost performance) as power sprayers and power dusters, even during the JPPA era, before the government budget was established; however, labor costs were overwhelmingly cheaper (Table 8). Among the various expenditures, helicopter spraying costs (the sum of machine depreciation and oil costs) were approximately three to four times higher than ground spraying (power sprayer and duster), but labor costs and their proportion in the total cost were significantly lower owing to the relatively low cost of chemicals for helicopter spraying and the overwhelmingly high efficiency in terms of the sprayed area. It is undeniable that the economic efficiency of helicopter spraying has increased further with the rise in government budgets and labor costs since the establishment of JAAA, considering the rapid increase in the area of aerial spraying (Figure 2). For example, in Akita Prefecture, the cost to farmers per 10 acres using the pesticide Lovesidesol for rice blast control around 1980 was 1,075 to 1,128 yen for ground spraying, but only 696 yen (including a subsidy of 111 yen) for aerial spraying, which is 60% of the cost of ground spraying (Shadan Hojin Norin Suisan Koku Kyokai 1987, 113).

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9 Looking at the contracting organizations in each of the 46 prefectures in 1967, JA and NOSAI in municipality were the largest numbers, with 22 regions, followed by the prefectural Federation of Agricultural Cooperative Association (JA-ZEN-NOH) with 14 regions, the prefectural Federation of Agricultural Mutual Aid Association with 4 regions, the prefectural Central Union of Agricultural Co-operatives (JA-ZENCHU) with 1 region, and other 5 regions (Norin Koku Gijutsu Handobukku Henshu Iinkai 1968, 290-291).

10 The difference with the long-distance air transport in Table 7 is probably because the budget included administrative costs such as organizing a work schedule.

Table 8 Comparison of helicopter aerial and ground spraying in 1962

Pest control equipment	Workers	Area sprayed once (ha)	Spraying area per person per day (ha)	Cost per 10a (yen) (rice blast disease)				
				Pesticides	Machine depreciation	Oil	Labor	Total
Shoulder-mounted sprayer	1	0.2~0.3	0.2~0.3					
Backpack sprayer	1	0.3~0.4	0.3~0.4					
Power sprayer	5~7	2.0~3.0 (8 hours)	0.4~0.6	130	40	20	73~103	263~293
Manual duster	1	0.5~1.0	0.5~1.0					
Duster	1~2	2.0~3.0	0.5~1.5	210	30	10	44~59	294~309
helicopter	10~20	150~200 (5 hours)	10~15	140	130~150		3~6	276~296

Source: Endo Takeo, Kuchu sanpu no koka to mondaiten (Effects and problems of aerial spraying), *Shoku Bustsu Boeki (Plant Protection)*, 1962, 16-3.

Second, since the establishment of the JAAA in 1962, amid an increase in budget, the number of operating companies and aircraft in operation per company, alongside the growth of the number of aircraft ownership and operation centred on Kawasaki Bell47, Hughes, Hiller, and Bell, which were small-size hericopters, increased significantly by the 1980s, except for around 1970 (Figure 9). Although not shown in Table 7, in 1963, the MAF requested that the Japan Development Bank provide financing for airlines'

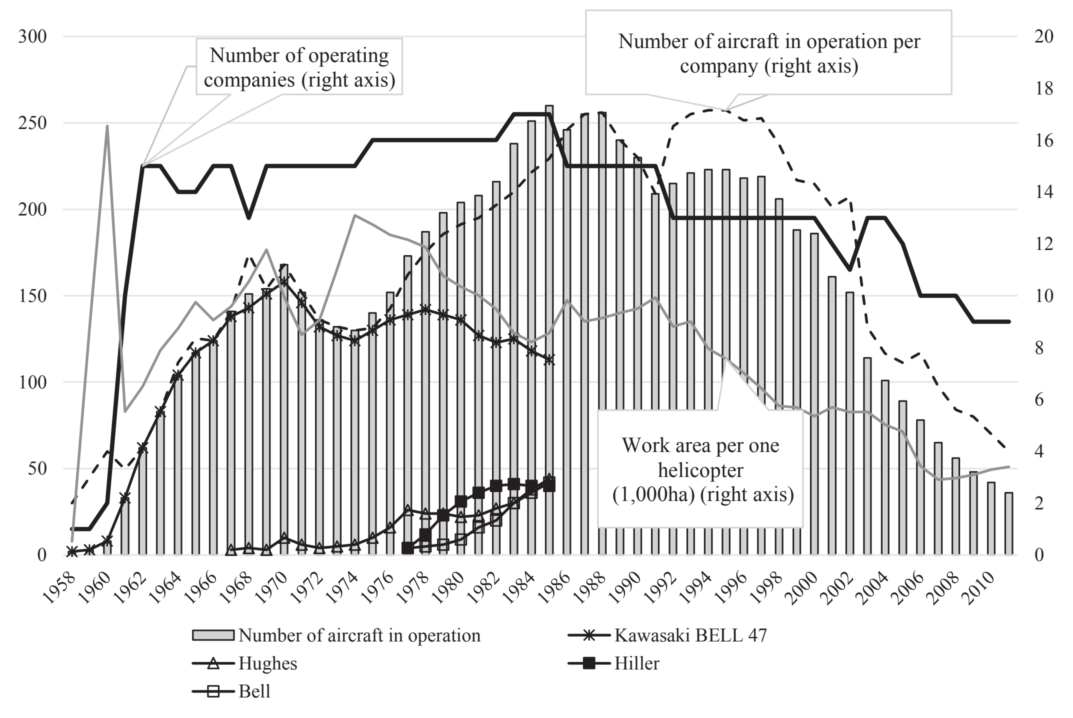

Figure 9

Number of helicopters owned by helicopter operators and number of helicopters in operation for pesticide spraying

Source: Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business), shadan hojin norin suisan koku kyokai, 1987; Norin suisan koku jigyo 50-shunen kinen-shi (Agricultural, Forestry and Fisheries Aviation Business 50th Anniversary Book), shadan hojin norin suisan koku kyokai, 2013 (All data provided by norin suisan koku kyokai); Appendix 1.
Note: Number of aircraft in operation was used for pesticide spraying.

helicopter purchases as a measure to increase the number of helicopters, and mediated the purchase of helicopters and spraying equipment (Hidetsugu Ishikura 1963, 4; Shadan Hojin Norin Suisan Koku Kyokai 1987, 14-15).

The Nippon Agricultural Helicopter, which had the largest number of helicopters in operation in 1962 with 12 (Takeo Endo and Yuu Naito 1963, 104), ordered two from the US and ten from Kawasaki Heavy Industries at the same time as it was established in March 1961, in tandem with the MAF's move to establish the JAAA (Shadan Hojin Norin Suisan Koku Kyokai 1987, 191). However, not all airlines have begun spraying pesticides. For example, Asahi Helicopter, originally founded in 1952 as Asahi Airlines, became Japan's second-largest helicopter operator by 1962, with nine helicopters surpassed only by the Nippon Agricultural Helicopter (Asahi Helicopter 1978). In its early years, the company struggled to find a clear direction, primarily by conducting low-altitude flights for advertising and aerial photography. However, a pivotal moment came in 1956 when Asahi participated in a forest pest eradication project in Hokkaido, providing a valuable insights into business management. Following a successful pesticide spraying test in Kanagawa in 1958, the company started its business in three other prefectures, including Nagano. In 1960, agriculture and forestry-related services centered on pesticide spraying became "Asahi's core revenue source". Nakanihon Aircraft, which held four helicopters in operation in 1962, also focused on passenger transportation in the early 1960s and had been "not very enthusiastic about agricultural and forestry aviation" (Shadan Hojin Norin Suisan Koku Kyokai 1987, 191-192).

The JAAA also played an important role in resolving the helicopter shortage. Based on the government budget, the JAAA acquired 3 helicopters in 1965 (all Bell), 3 in 1967 (all Bell), 1 in 1974 (Hughes), 4 in 1975 (2 Bell and 2 Hughes), and 4 in 1979 (2 Hiller and 2 Enstrom 280C), totaling 15 helicopters (8 Bell, 2 Hiller, 3 Hughes, 2 Enstrom) (Shadan Hojin Norin Suisan Koku Kyokai 1987, 272-282). Overall, JAAA's helicopters, similar to the overall trend, shifted from small, mostly domestically manufactured Bell G3B-KH4 to medium-sized American helicopters, such as Hughes and Hiller. The main reason for this was an increase in the payload[11]. Rising aircraft prices and the need to develop fields other than agriculture have become major problems. The domestic production of helicopters began in 1952 when Japan Machinery Trading (Mitsui & Co., since 1960) introduced technology from the American company Bell and outsourced the production to Kawasaki Machine Industry (now Kawasaki Heavy Industries) (Shokubutsu Boeki Jigyo Nijushunen Kinenshi Henshuiinkai 1971, 86). Incidentally, as of 1986, 262 helicopters in operation in the agriculture and forestry sector were manufactured in three countries: Japan, the US, and France, but of the 230 helicopters whose country of manufacture was clearly identified (the remaining 32 were Hughes 500 models with "Japan and the United States" written on them), 131 were from the US, 20 from France, and 79 from Japan (Shadan Hojin Norin Suisan Koku Kyokai 1987, 46).

As the number of helicopters in operation increased until the mid-1980s, the average spraying area per helicopter increased significantly from 6,000 ha in the early 1960s to 13,000 ha in 1974 but has been on a rapid downward trend since then (see Figure 9). From a management perspective, where an annual spraying area of approximately 10,000 ha per helicopter was necessary for independent (profitable)

[11] In other words, medium-sized helicopters are lighter than small helicopters in terms of payload weight ratio (payload weight /total weight × 100), but the higher payload weight ratio means that it can spray more efficiently (Shadan Hojin Norin Suisan Koku Kyokai 1987, 48).

management (Ishikura Hidetsugu 1963, 1; Shadan Hojin Norin Suisan Koku Kyokai 1987, 198), the annual spraying area per helicopter had been decreasing since the late 1970s but had remained at the 10,000 ha level by 1981. Another reason was that the dusters were replaced by sprayers (for liquid application), granular applicators, ULV systems, and microgranule applicators as the dust changed to low-volume sprays, liquids, and liquids (low-volume) (see Figure 5 and 6). Such low-volume application technology meant that the same aircraft could apply a larger amount of a single load (see below). In any case, in particular, since the early 1980s, management has been under pressure to diversify into businesses beyond pesticide spraying.

Third, "General training" on agricultural and forestry aviation-related technologies was first planned by JPPA in 1961, and there were two training courses for airlines and implementing organizations, which JAAA inherited from 1962 onwards (Shokubutsu Boeki Jigyo Nijushunen Kinenshi Henshuiinkai 1971, 85) (Table 9). By 1984, the total number of participants in the airline training course in basic knowledge training for new employees (pilots, maintenance, and sales staff) was 2,227. There were also maintenance technology training courses that began in 1973 and training courses for existing employees,

Table 9 Pilot training and training in the agricultural and forestry aviation business

	Graduates of helicopter pilot training course	Special training participants		General training								
				Airlines				Implementing organizations				
									Agriculture			
		New employees	Existing employees		Pilot	Maintenance	Sales		Prefecture	Airlines	Pesticide company	Forestry
1961				103	41	37	25	53	n/a	n/a	n/a	
1962				118	43	41	59	134	111		23	
1963		13		131	49	46	27	276	245		31	
1964	5	29		126	32	28	45	250	236		14	
1965	11	24		96	33	34	20	303	281		22	
1966	8	19	22	75	25	25	22	255	250		5	
1967	6	17	26	63	21	25	15	279	256		23	86
1968	5	18	24	81	37	30	14	110	104		6	84
1969	7	22	16	163	59	65	35	144	138		6	156
1970	8	23	14	187	70	82	24	127	108		19	208
1971	9	23	14	92	35	49	8	201	98		21	116
1972	8	18	30	69	25	34	14					259
1973	9	13	31	61	25	18	18	141	118		23	377
1974	8	18	12	58	22	18	18	225	194		31	178
1975	9	13	24	50	18	20	12	331	234	52	39	241
1976	10	17	15	57	16	31	10	327	235	47	34	86
1977	10	17	15	82	29	39	14	272	219	23	30	173
1978	10	18	12	101	44	39	18	317	233	28	56	242
1979	9	18	12	99	44	39	16	256	183	35	38	459
1980	9	18	12	91	27	55	9	304	229	37	38	326
1981	10	15	20	70	20	40	10	320	239	36	45	296
1982	9	12	28	81	30	39	12	269	187	33	47	109
1983	8	18	12	73	24	37	12	388	297	27	59	147
1984	8	12	28	100	29	49	22	395	295	28	70	302
1985	7	15	20	n/a	n/a	n/a	n/a	420	318	34	68	170
Total	183	410	387	2,227	798	920	479	6,097	4,808	380	748	4,015

Source: Shadan hojin norin suisan koku kyokai, Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business), 1987, 62; Norin suisan koku kyokai, *Norin suisan koku nenpo (Annual Report of Agriculture, Forestry and Fisheries Aviation (various editions)*.

Note: The total for Agriculture General training included prefectures, airlines, pesticide companies, and others.

but the number of participants is unknown (Shadan Hojin Norin Suisan Koku Kyokai 1987, 66). However, according to Table 9, the number of participants in general training courses related to agriculture for implementing organizations reached 6,097. The largest number of participants were employees of "prefectures" (including municipalities, implementing organizations, etc.).

The pilot shortage problem has been a pressing issue since the launch of the JAAA. At first, the pilots for Japan Agricultural and Forestry Helicopters were headhunted from the Self-Defense Forces, but their salaries were high at 70,000 yen compared to the average cash salary of 26,626 yen in Japan in 1961, and the company was constantly struggling to keep up with the rising salaries (Shadan Hojin Norin Suisan Koku Kyokai 1987, 191; Haruhiko Kawamura 1987, 122). The Self-Defense Forces also began to impose strict regulations in fiscal year 1962, as a large number of pilots transferred out disrupted defense plans (Shadan Hojin Norin Suisan Koku Kyokai 1987, 59). The pilot training system at the JAAA, based on the MAF budget (see Table 7), began in 1964. Prior to that, the Ministry of Transport, the Self-Defense Forces, and the Ministry of Finance discussed ways to resolve the extreme shortage of civilian pilots, and in 1962, the first civilian pilot training by national agencies was commissioned to the Self-Defense Forces. However, there was no system for recruiting students for this program; therefore, it was not possible to secure suitable personnel, and the airlines were solely responsible for covering the program costs. Consequently, despite the target of 20 students per year, only 11 were enrolled in 1962 and just 7 in 1963.

In light of this situation, in 1964, the JAAA began recruiting trainees with the academic ability of a junior college graduate or higher and started a pilot training system in which the Self-Defense Forces was consistently outsourced from the basic education course (6 months) to the fixed-wing piloting course (6 months) and the rotary-wing piloting course (6 months). The training system of outsourcing to the Self-Defense Forces continued until 1977. This was because the Self-Defense Force was no longer able to take charge of the basic and fixed-wing courses owing to the renewal of the training aircraft in the Self-Defense Force. Instead, in 1978, the JAAA adopted graduates of two-year basic education and fixed-wing training courses at the National Defense Academy and changed the training system to outsource five months of rotary-wing piloting training to the Defense Agency. The total number of pilots trained through this program was 183 by 1985 (Table 9). As of June 1, 1986, the status of these pilots was as follows: 153 had JAAA member airlines, 10 had other airlines, 12 were private pilots, 2 had retired from piloting, and 6 had died (Shadan Hojin Norin Suisan Koku Kyokai 1987, 63). This shows that the JAAA pilot training system played an enormous role in securing pilots for member airlines.

Finally, the R&D budget for new technologies was composed of the "New technology test and development" (which was changed to the "technology rationalization test project" in 1976) and the "Technology R&D facility improvement project." In particular, the "New technology test and development" grew from approximately 10 million yen in the 1960s to over 30 million yen in 1980, and in 1983, it surpassed the "Operation comprehensive countermeasures project (formerly the "long-distance air transport" budget)," and has continued to account for the largest amount of the government budget ever since. It is clear that new technology testing and development have been sustainably promoted with a long-term focus, leading to the Technology Research and Development Facility Development Project budget, which aimed to establish the Agriculture and Forestry Aviation Technology Center (completed in in 1974 in Komoro City, Nagano Prefecture).

In JAAA's book *25 Years of Voyages in the Agricultural, Forestry and Fisheries Aviation Industry*, Shadan Hojin Norin Suisan Koku Kyokai (1987, 84) argued that the trends of the new technology test and development had two main periods: 1) the period from 1962 to 1965 was a period for expanding into new fields, such as weeding, direct seeding of rice, field crops, fruit trees, forestry-related pest control, and the fisheries industry, where fertilization was used to enhance the color and luster of seaweed; and 2) from 1966 onwards, testing and development focused on micro-spraying.

As previously mentioned, there was a temporary decline in the number of aircraft in the early 1970s (Figure 9). This was that problems such as the acute toxicity of pesticides, contamination of crops, soil and water systems, and adverse effects on wildlife have been severely criticized since the late 1960s, as pointed out at the beginning of Section 2 (Pesticide in the Aerial Control). Similarly, in Japan, from the late 1960s onwards, social concerns and criticisms regarding the problem of pesticide residues in food, water, and soil contamination caused by pesticides commonly used in aerial spraying, such as BHC, DDT, parathion, and mercury dust, rapidly increased (Nihon Shokubutsu Boeki Kyokai 1980, 109-113; Hiroki Ota 2015, 46-47). The Food Sanitation Law was revised in 1968; the sale of organic mercury agents was banned in 1970; and the sale of DDT, BHC, etc., was banned in 1971, along with major revisions to the Agricultural Chemicals Regulation Act. The second period of new technology testing and development at the JAAA was carried out proactively precisely at a time when social criticism of such pesticides was growing. Since a temporary decline in the early 1970s, the number of aircraft operating for aerial pesticide spraying has increased (see Figure 9). Technological innovations in the spraying apparatus kits were strongly supported by new technology testing and development.

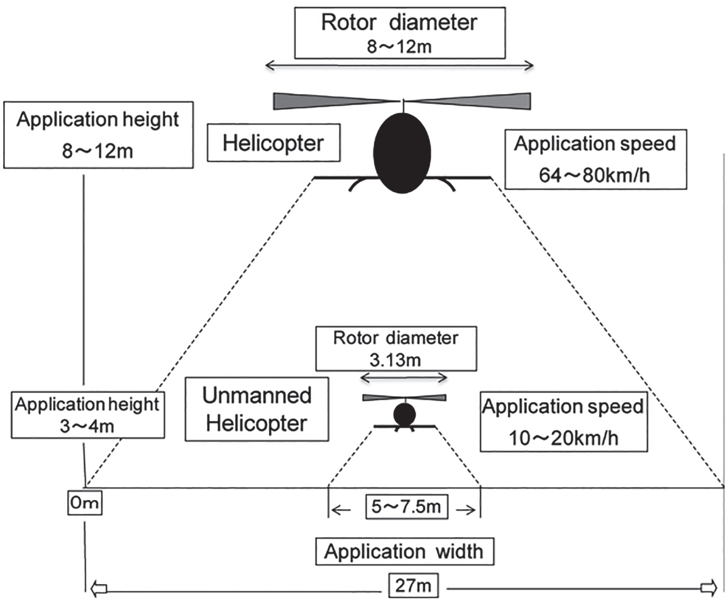

Figure 10

Size and application manual of helicopter and unmanned helicopter application

Source: Haga Toshirou, "Recent advances and future prospects of aerial applications and unmanned helicopter applications," Japan Agricultural Aviation Association, 2013, 38 (2).

Helicopter spraying is characterized by the downwash of the main rotor with a rotor diameter of 8–12 m, which allows the pesticide to be sprayed evenly across the application width, and there is a strong demand for spraying equipment that can effectively utilize the downwash (Shiro Yamamoto 1982) (Figure 10). The importance of spraying apparatuses is confirmed by the fact that the Sprayer Apparatus Certification Committee was quickly established immediately after the establishment of JAAA (Shadan Hojin Norin Suisan Koku Kyokai 1987, 57). To standardize the apparatuses' capacity for each model of each company, the committee certified the capacity of all apparatuses used in spraying that year based on strict certification standards. The following were specified: 1) the time required to open and close the gate shutter, 2) the start and end times of dust discharge, 3) fluctuations in the rate of dust discharge, 4) interruption of dusting and dripping, and 5) measurements of the air volume and wind speed of the nozzle. Incidentally, as aerial spraying expanded, a growing number of pesticide manufacturers have entered the aerial spraying pesticide market. However, differing standards between companies became a problem at spraying sites, and so the JAAA established the Spraying Equipment Materials Committee, consisting of engineers from airlines and pesticide companies, as well as academics and other experienced personnel, almost at the same time as the Spraying Equipment Certification Committee (Shokubutsu Boeki Jigyo Nijushunen Kinenshi Henshuiinkai 1971, 88-89).

Table 10 lists the types of certifications by company and pesticide by the Spraying Equipment Certification Committee from 1963 to 1979. From 1963 to 1965, Kawasaki Heavy Industries, Asahi Helicopter, and All Japan received certifications for 17 types of spraying equipment, mainly for dust. Since 1966, the number of type-certified companies rapidly increased to 9 companies in 1970 and 12 companies in 1979, and the type of apparatus not only shifted from dust to liquids and granules[12] but also showed a rapid increase in ULV and micro-granules in the 1970s. According to JAAA statistics, the companies or organizations that receive type certification change from "manufacturer" to "developer" to "applicant," but as shown in the list, the companies or organizations responsible for manufacturing and developing the apparatus are mostly airlines involved in aerial spraying, in addition to the pioneer in helicopter manufacturing (Kawasaki Heavy Industries) and JAAA (No.10).

The first duster apparatus in Japan was developed in 1955 by Kawasaki Aircraft Industries (since 1969, Kawasaki Heavy Industries) with a model made by Bell, an American company. Research into this technology has accelerated ever since (Shokubutsu Boeki Jigyo Nijushunen Kinenshi Henshuiinkai 1971, 87). The advantages of the duster are that organic mercurials are highly effective in controlling neck node blasts, the sprayed rice plant can be identified from the air, and there is no need to mix pesticides (Naoki Hatai 1960; Kazuo Goto 1967). However, the storage of dust formulation is challenging. When filling the apparatus tank with dust, the inclusion of solid objects such as paper bags, can easily cause the apparatus to break down (Takemoto Kenji 1962, 9). In addition, because they are easily affected by the wind, the problem of drifting to residential areas and crops grown in the target areas has become increasingly problematic since the late 1960s. (Norio Saito 1969; Nihon Shokubutsu Boeki Kyokai 1980, 72; Toshirou

[12] Granules are used widely in agricultural and forestry aviation to spread rodenticides, herbicides, and fertilizers, among others, but their use in rice fields has been extremely rare. In the early 1980s, their use increased for the control of rice leaf blast, but it was almost exclusively for ground control. The application (30 kg per hectare) was less efficient than that of ultra-low volume (0.8-3 kg) or liquid low volume (8 kg) (Yamamoto Shiro 1982, 550).

Table 10 List of type certifications for spraying apparatuses for agricultural, forestry and fisheries aviation

	Company name (development, manufacturing, application)	1963-65					1966-70					1970-79					Total					
		A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E	
1	Kawasaki Heavy Industries	6	3	2			1	2	2				1	2	1		7	6	6	1		20
2	Asahi Helicopter*	3	1					2	3				2	3	1		3	5	6	1		15
3	All Nippon Airways*	2						1	3								2	1	3			6
4	Tohoku Sangyo Airlines*						1	1									1	1				2
5	Toa Domestic Airlines*								2					1					3			3
6	Nakanihon Airways*								2					1					3			3
7	Nippon Agricultural Helicopter*								2			1	2		1	1	1	2	2	1	1	7
8	Imperial Airlines*							1										1				1
9	Setouchi Airlines*								1										1			1
10	Agricultural Aviation Association*												2		2	2		2		2	2	6
11	Hankyu Airlines*											1		1		1	1		1		1	3
12	Nishi Nippon Airways*													2					2			2
13	Musashi Airways*											1	1				1	1				2
14	Musashi Giken													2					2			2
15	Asia Aircraft														1					1		1
16	Santoku Aviation Electrical Equipment												1					1				1
	Total	11	4	2			2	7	15			3	9	12	6	4	16	20	29	6	4	75

Source: Norin suisan koku kyokai, *Norin Suisan koku nenpo (Annual Report of Agriculture, Forestry and Fisheries Aviation)*, 1965-1979.
Note: A: Dust, B:Liquid, C: Granule, D: Ultra low volume, E: micro-granule. "*" indicates a company or an organization that owns a helicopter and is engaged in aerial spraying.

Haga 2013, 225).

Considering the problems with dust, manufacturers began developing spray kits for liquids relatively early. As shown in Table 10, Kawasaki Heavy Industries obtained type approval for three types of spray kit certification between 1963 and 1965. In his report in March 1962 regarding aircraft and spraying apparatus, Takemoto wrote that liquid spraying, which is inexpensive, less susceptible to wind, and has stable fall conditions, was popular in the US, but Japan was lagging (Kenji Takemoto 1962, 9).

The development of liquid apparatus began in earnest in the late 1960s. In April 1968, the Ultra Low Volume Apparatus Prototype Specialist Committee was established, and with additional grants for the prototype of the ULV apparatus three times in 1968, 1971, and 1974, prototypes and experiments continued throughout the country (Shadan Hojin Norin Suisan Koku Kyokai 1987, 16, 277-280). In 1971, a dust apparatus (30kg per hectare) that could minimize drift was put into practical use, but it did not become widespread due to the successive development and practical use of liquid apparatus (30 times diluted 1 ha, 30 liters pesticide), low volume apparatus (8 times diluted 1 ha, 8 liters), and ULV apparatus (0.8 to 3 liters per hectare of undiluted solution) in the early 1970s (Haga Toshirou 2013). In particular, an ultra low-volume apparatus is the most efficient and economical spraying method that takes advantage of aerial pest control because the undiluted solution is sprayed as is. The apparatus was a rotary atomizer, which 1) enabled the spraying of highly viscoelastic pesticide formulations using a gear pump type pump and nozzle and 2) enabled the spray mist to have a uniform particle composition of around 100 μm due to the shape of the nozzle. Low-volume liquid spraying began with tests in 1972 and was put to practical use in 1975. This spraying method 1) used a nozzle for ULV, 2) the viscoelasticity of the diluted solution with water was lower than that of ULV, and 3) the pumps were gear pumps and centrifugal pumps. This method has been used in spraying technology to control unmanned helicopter pest control.

Conclusion: Achievements and Limitations

The above analysis of the development of aerial pesticide spraying in Japan's agriculture during the period of high economic growth clarifies the processes of "incremental innovation" and "induced innovation" while focusing on the interrelationship between the agricultural and the non-agricultural sectors. Three key characteristics emerge from the analysis.

First, aerial pesticide spraying in Japanese agriculture began in the early 1950s with the introduction of fixed-wing aircraft technology from Western countries, but it has since rapidly evolved into a unique spraying method using helicopters. The primary reasons for this was that the location conditions of Japanese agriculture required short runway distances for takeoff and landing, large pesticide load capacity, stable machine neutrality at low speeds, ability to climb quickly, wide visibility, small turning radius, stability in sharp turns, ability to fly and spray with a single pilot, and ability to utilize downward air currents, among others, and helicopters were suitable for such requirements according to repeated experiments.

Second, the transfomation and diffusion of MAVs were deeply related to Japan's plant protection system, which is said to have "world-class standards." This system was established during the postwar reconstruction period with the MAF at the helm, and with the aim of increasing food production, creating an organization whose tasks included pest control and forecasting in villages all over the country. Among these, pest control stations and the JAAA played important roles in maintaining close ties with each other. In particular, although JAAA was established under the initiative of the MAF, its momentum was born from the spontaneous activities of local experimental stations, plant protection stations, and private plant protection associations (JPPA) that recognized the importance and effectiveness of aircraft control in the eradication of pests and diseases, and in that sense, the establishment of JAAA can be characterized as a bottom-up organization.

Third, the proactive participation of airlines in the non-agricultural field of pesticide spraying was extremely important for the development of the JAAA. Aerial spraying is suitable as a joint control method for timely pest control and is also far superior to ground spraying in terms of cost. Airlines were not only responsible for pest control but also for developing and manufacturing spraying apparatuses. Particularly, airlines continued to develop and manufacture spraying apparatuses to promote the change from dust to low-volume liquid spraying, not just the dusts of the 1960s, before social criticism of dusts due to drift and other factors increased. Another example is Mitsubishi Heavy Industries, which, although not directly involved in pesticide spraying, supplied helicopters to airlines entering the pesticide spraying business and played a vital role as a pioneer in the development and manufacture of pesticide spraying apparatus. Behind the wide range of airlines' aggressive activities in pesticide spraying, as described above, was the ever-growing need for pesticide spraying, along with the development of new aviation uses, subsidies for charter fees, pilot training, and so on, all of which were backed by the MAF's increasing budget.

As mentioned above, MAVs in agricultural spraying can be said to have reached a great milestone during the period of high economic growth through "incremental innovation" such as helicopter aerial spraying and spraying apparatus, which were induced by the different location conditions of Japan's agriculture compared to the US, while introducing aviation technology based on the world-class plant protection system. However, helicopter-based MAVs were gradually reaching their limitations. One is the deterioration of profits in airlines' pesticide spraying field. As mentioned above, pesticide spraying was strongly seasonal and concentrated from June to August. In addition, owing to the entry of many airlines, the spraying area per helicopter rapidly fell below 10,000 ha, which has been considered the profit limit since the late 1970s. In addition, the efficiency of pesticide spraying using low-volume liquid or ULV spraying has progressed, and although it played a significant role in precision pesticide spraying, the annual spraying time per helicopter is thought to have decreased. A simple calculation of the annual pesticide spraying hours per helicopter based on the number of helicopters in operation showed a decreasing trend since 1970. The number peaked at 248 hours (130 helicopters) in 1974, then declined to 218 hours (218 helicopters) in 1980, and further to 169 hours (238 helicopters) in 1985 (Shadan Hojin Norin Suisan Koku Kyokai 1987). The Helicopter Use Study Group pointed out this problem in the 1980s as "low operational efficiency (about 200 hours)" (Helikoputa Riyo Kenkyukai 1988, 190). Considering that the spraying fee and air transport fee are paid per hectare and per hour, respectively, according to the "Calculation Guidelines for Long-Distance Travel Distances," it can be said that the revenue from helicopter pesticide spraying has passed the stage of significant growth, even with subsidies from the MAF. As shown in Table 11, sales of pesticide spraying had plateaued during the early 1980s. Instead, material transportation grew significantly more than pesticide spraying, and personnel transportation began to become a major business. Second, the safety of helicopters for pesticide spraying has been questioned frequently. As shown in Table 12, the number of accidents per 5,000 hours has been decreasing; however, in the early 1980s, it was still over 1.0. The number of serious injuries and deaths was high by the mid-1980s. The Helicopter Use Study Group pointed out that the rate of "about one accident per 5,000 flight hours was a high accident rate that exceeds general aviation common sense" (Helikoputa Riyo Kenkyukai 1988, 41).

Table 11 Sales breakdown by helicopter category

	1981		1983		1985	
Number of businesses (companies)	n/a		18		17	
Number of aircraft (units)	n/a		413		463	
	million yen	(%)	million yen	(%)	million yen	(%)
Personnel transportation	856	3.3	785	2.9	1,413	4.5
Sightseeing	621	2.4	348	1.3	346	1.1
Material transportation	4,626	17.7	7,710	28.2	9,051	28.9
Pesticide spraying	8,406	32.1	8,044	29.4	8,931	28.5
News coverage	3,840	14.7	3,026	11.1	2,976	9.5
Patrol	3,793	14.5	3,261	11.9	3,018	9.6
Photography and other	5,665	21.6	3,423	12.5	5,014	16.0
Operated by other companies	728	2.8	787	2.9	597	1.9
Total	26,206	100.0	27,384	100.0	31,346	100.0

Source: Helikoputa riyo kenkyukai, *Mirai o hiraku herikoputa (Helicopters Opening Up the Future)*, Chiiki koku sogokenkyusho, 1988.

Table 12 Number of helicopter pesticide spraying accidents in the agriculture and forestry sector

	Number of accidents and casualties							Hours of pesticide spraying operations (hours)	Number of accidents per 5,000 hours (cases)
	Contact with overhead lines, etc.	Takeoff and landing	Machine breakdown	Other	Total (cases)	Number of serious injuries (people)	Number of deaths (people)		
1955				1	1		2	n/a	n/a
1956					0			n/a	n/a
1957					0			n/a	n/a
1958	1				1	1	2	353	14.2
1959			1		1			617	8.1
1960	1			1	2		1	1,937	5.2
1961	4			1	5			3,235	7.8
1962	6			1	7	3	1	9,547	3.7
1963	8	2	2		12	7	2	14,915	4.0
1964	8	1	3	1	13	3		19,883	3.3
1965	13	1	6		20	5	4	22,790	4.4
1966	6	1	4		11	3		23,200	2.4
1967	9	1	3	2	15	7	1	29,869	2.5
1968	5		7	2	14			35,174	2.0
1969	3	1	5		9	2		38,394	1.2
1970	10	1	3	1	15	3	3	31,158	2.4
1971	3	2			5		3	24,697	1.0
1972	1	3	1	2	7	2		24,592	1.4
1973	4	2	3	3	12	4	3	29,398	2.1
1974	5	1	3	1	10	3	1	31,876	1.6
1975	4	1	4	4	13		1	34,627	1.9
1976	5		3	5	13		5	36,642	1.8
1977	2	1	2		5	2		41,851	0.6
1978	4	1	6	1	12	2	1	40,333	1.5
1979	4	5	1	1	11	2	1	41,506	1.4
1980	4	4	2	2	12	2	2	44,425	1.4
1981	4	1	2	2	9	5		42,603	1.1
1982	4		1	1	6		1	41,053	0.8
1983	2	1		2	5	1	1	40,243	0.6
1984	1	1	1		3		1	42,217	0.4
1985	2	1	2	3	8	3	1	44,034	0.9

Source: Norin suisan koku kyokai, Norin suisan koku nenpo (Annual Report of Agricultural, Forestry and Fisheries Aviation) (Various years); Norin koku gijutsu handodukku henshu iinkai, Norin koku gijutsu handobukku (Agricultural and Forestry Aviation Technology Handbook), Chikyu shuppan, 1968. Shadanhojin norin suisan koku kyokai, Norin suisan koku jigyo nijugonian no koseki (25 years of Agricultural, Forestry and Fisheries Aviation Business), 1987.

In response to the achievements mentioned above and the limitations of helicopters, JAAA inherited the achievements of MAVs but independently came up with a new development project to overcome their limitations: UAVs. A detailed analysis of this point will be presented in another article[13].

[13] For research on UAVs in the agricultural sector, please see Fu Cho and Kyohei Hirano (2024), and Fu Cho (2024) presented at the 2024 European Business History Conference in Lisbon (https://www.ebha2024.pt/wp-content/uploads/2024/07/EBHA-2024-Programme.pdf).

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Appendix 1. Trends in the Area of Agricultural and Forestry Pesticide Spraying by Manned and Unmanned Aircraft (ha)

Year	Manned aircraft											Unmanned helicopte					Unmanned Multicopter				
	Agriculture					Forestry（nation & private）						Agriculture					Agriculture				
	Rice	Fruit trees	Field Crops	Livestock	Total (Fixed-wing)	Pests/ Insects	Animal damage	Afforestation	Soil control	Fertilization	Total (Fixed-wing)	Rice	Wheat	Soybeans	Other	Total	Rice	Wheat	Soybeans	Other	Total
1953						203					203 (203)										
1954						6,585					6,585 (4,900)										
1955						61,575					61,575 (26,352)										
1956						15,186					15,186 (425)										
1957						240					240										
1958	1,045				1,045																
1959	4,244				4,244	1,210	20,764				21,974										
1960	17,915				17,915	2,971	111,485				114,456										
1961	99,309	1,922			101,231	468	80,674				81,142 (200)										
1962	272,895	1,162	700		274,757	11,652	116,652				128,137										
1963	515,180	650	4,479		520,309	11,776	117,285		4		135,065										
1964	684,167	4,838	5,992	455	695,452 (180)	19,004	193,874	365	6		213,249										
1965	832,744	7,572	3,350	800	844,466	18,019	277,566	447	10		296,042										
1966	841,599	6,947	3,521	396	852,463	32,292	233,692	4,053	169		270,206										
1967	955,070	11,026	3,631	490	970,217	42,032	329,071	9,467	408		380,978										
1968	1,106,724	13,861	5,805	1,634	1,128,024	52,689	391,617	19,858	119		464,283										
1969	1,244,153	14,356	7,370	3,386	1,269,265	60,456	452,206	31,163	103		543,928										
1970	1,007,930	12,416	7,719	6,517	1,034,582	52,246	551,575	32,314	178		636,313										
1971	681,208	12,383	10,553	41,501	745,645	32,372	494,561	17,839	338		545,110										
1972	739,882	8,729	8,112	49,773	806,496	14,269	407,709	3,966	161		426,105										
1973	831,558	15,655	13,659	59,341	920,213	34,693	495,404	5,384	275		535,756										
1974	971,458	10,258	15,316	70,617	1,067,649	64,040	565,044	6,263	275		635,622										
1975	1,150,248	10,770	18,056	66,861	1,245,935	93,305	437,645	7,014	222		538,186										
1976	1,279,325	8,239	27,628	50,279	1,365,471	130,413	373,229	6,916	300		510,858										
1977	1,469,289	10,892	22,778	38,953	1,541,912	190,429	363,229	7,693	589		561,940										
1978	1,438,057	10,592	44,730	38,714	1,532,093	227,175	453,025	8,090	593		688,883										
1979	1,408,006	9,551	59,244	38,293	1,515,094	270,184	333,279	10,699	791		614,953										
1980	1,414,514	8,593	49,943	33,866	1,506,916	291,094	302,382	9,559	873		603,908										
1981	1,361,889	9,610	54,427	31,508	1,457,434	310,459	305,031	8,302	756		624,548										
1982	1,385,512	8,022	47,756	16,714	1,458,004	290,727	295,077	4,398	444		590,646										
1983	1,404,915	9,632	42,089	17,333	1,473,969	286,257	274,901	2,527	369		564,054										
1984	1,503,701	9,082	40,872	16,945	1,570,600	278,066	209,637	3,849	550		492,102										
1985	1,610,899	11,369	39,525	13,626	1,675,419	314,299	232,123	4,412	466	652	551,952										
1986	1,727,749	10,381	37,254	10,198	1,785,582	287,674	337,959	4,120	563	662	630,978										
1987	1,735,947	10,704	40,869	9,328	1,796,848	253,638	242,990	3,227	555	487	500,897										
1988	1,741,211	10,016	38,695	7,961	1,797,883	258,679	278,120	2,943	571	333	540,646										
1989	1,696,533	8,780	37,711	7,491	1,750,515	253,837	231,536	3,695	627	245	489,940	333				333					
1990	1,668,189	7,167	35,377	4,792	1,715,525	241,127	225,084	3,886	532	356	470,985	2,606				2,606					

1991	1,622,389	6,317	30,917	4,044	1,663,667	219,297	187,166	3,598	451	239	410,751	6,159				6,159					
1992	1,478,590	5,773	27,505	3,060	1,514,928	206,888	167,194	3,708	660	336	378,786	18,349	20	102		18,471					
1993	1,597,280	5,442	25,634	3,185	1,631,541	186,206	169,468	2,563	543	166	358,946	37,754	37	164		37,955					
1994	1,394,580	5,232	21,160	3,127	1,424,099	175,235	171,414	2,037	453	456	349,595	71,058	61	134		71,253					
1995	1,328,433	4,602	18,920	3,146	1,355,101	159,960	169,011	2,003	381	202	331,557	110,127	110	337		110,574					
1996	1,201,684	4,682	16,959	3,070	1,226,395	158,218	142,571	2,136	203	197	303,325	145,030	320	1,232		146,582					
1997	1,129,415	4,212	16,699	3,122	1,153,448	119,192	130,942	1,676	207	311	252,328	186,252	739	2,131		189,122					
1998	942,171	3,951	13,423	3,756	963,301	107,168	112,761	1,021	123	203	221,276	215,261	2,560	8,391		226,212					
1999	826,859	3,753	9,205	9,205	849,022	100,889	119,040	568	261	177	220,935	254,496	7,042	14,607		276,145					
2000	776,851	3,920	7,093	7,093	794,957	94,649	105,548	472	109	116	200,894	303,926	9,935	23,774		337,635					
2001	708,382	1,698	7,567	7,567	725,214	91,719	100,581	300	89	38	192,727	342,037	14,421	32,079		388,537					
2002	649,083	313	7,896	7,896	665,188	81,146	91,042	87	116	54	172,445	382,015	19,184	38,023		439,222					
2003	451,533	431	5,616	5,616	463,196	79,564	86,102		45	23	165,734	474,263	38,966	49,577		562,806					
2004	346,321	386	8,517	8,517	363,741	65,088	78,499		36	30	143,653	541,927	46,521	48,597		637,045					
2005	287,171	384	6,502	6,502	300,559	58,334	64,844		29		123,207	611,520	47,280	51,270		710,070					
2006	146,126	193	6,014	3,986	156,319	48,311	63,070		56		111,437	692,450	57,120	50,270		799,840					
2007	89,327	193	6,000	2,686	98,206	34,301	56,558		67		90,926	750,910	58,940	56,870		866,720					
2008	73,697	193	7,500	2,181	83,571	28,641	53,545		63		82,249	776,940	63,920	65,490		906,350					
2009	57,759	190	7,500	1,670	67,119	24,012	57,430		29		81,471	808,616	59,950	54,878	6,866	930,310					
2010	51,158	189	7,500	1,524	60,371	20,959	57,020		21		78,000	838,156	60,730	57,905	6,459	963,250					
2011	45,249	194	7,500	1,233	54,176	19,567	48,656		11		68,234	851,822	61,351	51,409	6,556	971,138					
2012	44,055	186	7,500	1,223	52,964	18,647	58,657		10		77,314	884,308	63,626	52,906	6,202	1,007,042					
2013	n/a	n/a	n/a	n/a	n/a	n/a	n/a				n/a	n/a	n/a	n/a	n/a	n/a					
2014	38,696				48,369	16,136	58,959				75,126	928,786	60,954	52,748	7,348	1,049,836					
2015	36,039				37,625	15,642	56,405				72,053	923,365	70,989	56,059	7,565	1,057,978					
2016	34,539				35,925	14,035	56,334				70,369	910,341	65,932	59,021	10,728	1,046,022	586	0	97	1	684
2017	33,512				53,123	14,712	57,365				72,105	903,689	65,312	60,644	6,343	1,035,988	7,000	700	500	100	8,300
2018	32,701				52,157	13,862	51,909				65,798	885,142	62,804	57,762	8,042	1,013,749	26,308	2,120	2,168	423	31,020
2019	30,819				49,580	12,644	52,898				65,605	881,317	65,118	51,260	7,034	1,004,729	n/a	n/a	n/a	n/a	65,128
2020	30,045				32,050	12,081	51,630				63,762	880,551	56,582	51,384	6,958	995,475	n/a	n/a	n/a	n/a	119,500
2021	27,549				29,641	12,886	50,742				63,703	838,701	64,047	47,704	6,008	956,460	n/a	n/a	n/a	n/a	n/a
2022	27,261				28,783	11,896	50,897				62,860	747,159	53,330	48,078	9,999	858,566	n/a	n/a	n/a	n/a	n/a

Source: 1953-57: Hatai Naoki “Utilization of Helicopter for Plant Protection.” Japan Agricultural Research Quarterly, 1968, 3 (1); Shokubutsu boeki jigyo ni jushunen kinenshi shiryohen (Plant Protection Business 20th Anniversary Memorial Book Data Collection) , Nihon shokubutsu boeki kyokai, 1971; 1958-2012: 1) Norin suisan koku jigyo nijugo no koseki (25 Voyages of Agricultural, Forestry and Fisheries Aviation Business), shadan hojin norin suisan koku kyokai, 1987; 2) Norin suisan koku jigyo 50-shunen kinen-shi (Agricultural, Forestry and Fisheries Aviation Business 50th Anniversary Book), shadan hojin norin suisan koku kyokai, 2013 (All data provided by norin suisan koku kyokai). For information since 2014, it refers to 1) Mujin kokuki ni yoru noyakuto no kuchu sanpu no jisshi jokyo ni tsuite (Status of aerial spraying of pesticides, etc. by unmanned aerial vehicles), and 2) Yujin herikoputa ni yoru noyakuto no kuchu sanpu no jisshi jokyo ni tsuite (Status of aerial spraying of pesticides, etc. by manned helicopters) (both are references to "Information on pest control" on the Ministry of Agriculture, Forestry and Fisheries website). For the area sprayed by unmanned multi-rotors on 2019-2020, it refers to Nogyoyo doron no fukyu kakudai ni mukete (Towards expanding the use of agricultural drones) , Norin suisansho nosankyoku gijutsu jukyuka (Symposium to promote the use of unmanned aerial vehicles in the agriculture and forestry sector, December 17, 2021), published on the Ministry of Agriculture, Forestry and Fisheries website.