DEVELOPMENT OF SUPER WIDE SPREADER FOR DIRECT RICE SOWING IN WET PADDY FIELD

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ABSTRACT

The development and improvement of the originally designed direct rice sowing machine were carried out for the specific purpose of saving labor and increasing the efficiency of field operations in rice cultivation in the northern part of Japan. The prototype super wide spreader has a unique mechanism which propels rice seeds by compressed air and spreads them from the pivoting nozzle while the machine is in motion. The effective field capacity of sowing operation is about 6 ha/h. This spreader can also handle granular chemicals such as fertilizers, herbicides, pesticides and insecticides.

Key Word : Large sized paddy field, Direct rice sowing, Broadcast seeding, Wide spreader

I. INTRODUCTION

In rice production in Japan, falling rice prices because of recent free trade and the advancing age of farm workers requires the reduction of production costs and increasing labor saving technologies. Enlargement of paddy fields and development of highly efficient technologies suitable for direct rice sowing to cope with large sized paddy fields are important to solve those problems. From that point of view, several machines and techniques for different direct sowing methods are being designed in some prefectural, governmental research institutes and by private companies.

The objective of this research is to develop and to investigate the performance of labor saving technologies and innovative operation methods, especially coping with large sized paddy fields, in order to raise and stabilize the rate of emergence and establishment of seedlings which is the greatest problem of the direct sowing method in the northern part of Japan. The proposed technology is to spread seeds and other chemicals in a wider area at a faster rate.

In this paper, the outlines of the configuration and performance of the proposed super wide spreader are described. The results of adaptation and verification tests carried out in an actual farmer's field are also mentioned.

II. MATERIALS AND METHODS

2.1 Design concept of the spreader

In this study, the super wide spreader was designed under the conditions described below.

1) In field operation : The machine should be active while traveling in the paddy field. The traveling device will be a conversion of a commercialized farm vehicle such as a rice transplanter.

2) Broadcast seeding : Seeding method should be broadcast seeding. And the spreader should also handle other chemical materials in addition to Calper −Oxygen supplying chemical− coated seeds.

3) Wide operating width : Target operating width is 50 meters.

4) Automatic pivoting nozzle : The spreading nozzle should move on a pivot from side to side automatically by some electrical devices.

2.2 Method for spreading seeds and chemicals

Concerning the above constraints, the super wide spreader has been designed and improved. The spreading method adopted for this machine is the propulsion of rice seeds by compressed air from the pivoting nozzle while the machine is in motion in a wet paddy field (Fig. 1). In the pivoting nozzle, seeds are accelerated by high velocity air flow and blown out from the pivoting nozzle. Thus, it is possible to obtain a wider operating width such as 50 meters, so that a large area can be sown in a short period. There is no guide vane in the channel of the high speed seed flow mechanism, so that coated seeds will not be impacted and damaged. These are the most significant feature of the super wide spreader, and is different from typical commercial broadcasters which spread materials by centrifical force.

2.3 Configuration of the super wide spreader

The prototype super wide spreader developed in this study consists of a vehicle for traveling and a spreading apparatus mounted on it. The spreading apparatus includes a seed tank, a blower driven by a gasoline engine, a seed supplying valve, a spreading nozzle, a turning table driven by an electric motor, a base frame and some control devices. The configuration of prototype 5, later described in detail, is shown in Fig. 2.

The spreading nozzle is set on a turning table, and that is driven by a 24 volt DC motor and pivots from side to side with certain horizontal motion previously set up. There are removable magnet limitters set on the edge of the turning table and 2 limit switches beside the turning table in order to pivot automatically. One of the switches is to reduce the turning speed, and the other is to reverse the turning direction. These switches are set on each side of the turning table, and will be activated when the magnet limitter contacts them. Pivoting angle is settled by the position of the magnet limitters. The trajectory angle of the spreading nozzle is also variable, and is regulated by an electric cylinder. The trajectory angle is easily controlled by a control panel near at the operator's hand.

2.4 Process of improvement

Prototype 1 : The primary design of the super wide spreader was modified from a conventional Japanese rice transplanter. The transplanting apparatus that fits behind the transplanter was replaced with a knapsack power applicator with a multi-hole blow head. The applicator adopted was a material supplying device widely popularized in Japan, but the engine power, that was 2.5kW(3.4PS), was not enough to obtain a 50 meter spreading width. The turning table was driven by a mechanical linkage system and lacked limit switches, so that it was not easy to rearrange the pivoting width.

Prototype 2 : Prototype 1 was modified to satisfy the target conditions described in chapter 2.1. The blower and the engine were replaced with larger ones. The limit switches which enable to rearrange the pivoting angle were adopted. Rotating speed of the turning table, the volume control of the seed supplying device and trajectory angle of the nozzle were modified to be easily regulated. A tapered blow head was also adopted in place of a multi-hole blow head. This prototype 2 almost satisfied the primary objective constraints, and several field test were carried out (Kimura et al, 1991). A computer simulation for seed distribution using the theory of particle motion was also carried out (Murakami et al, 1991).

Prototype 3 : Capacity of the seed tank was enlarged. After some studies using prototype 2, it became clear that time for replenishing seeds was 40% of the total working time when the capacity of the seed tank was 40 liters. In prototype 3, the seed tank was replaced with that of a 120 liter tank and the turning table was strengthened. Then, several field experiments took place(Kimura et al, 1992). The experiments for automatic unmanned operation using laser beam and radio control were also attempted (Kimura et al, 1994).

Prototype 4 : Three large alterations were made. 1) A high-clearance type tractor was used as a traveling device, in order to cope with in-field operations such as chemical applications after crops grow taller. The adopted high-clearance tractor had a 60cm road clearance, a 7.0kW engine and a 4 wheel steering system. 2) All of the spreading apparatus were placed in front of the tractor, so that it became easier for the operator to observe the seeding process. The spreading apparatus was set by using an exclusive extension base frame, and 100kg counter weights were set in the rear end of the tractor. 3) The seed supplying valve was replaced with a rotary type, making it easier to regulate the volume of the seeds by controlling motor speed (Kimura et al, 1995).

Prototype 5 : The weight balance of prototype 4 was inadequate, so that the machine was not stable when it got into or got out from a paddy field and it was hard to steer in wet paddy fields. In prototype 5, the spreading nozzle with turning table is still set in front of the high clearance tractor. Though, the other apparatus, such as the seed tank, the blower, the engine for the blower and the material supplying valve were moved to rear end of the vehicle. In the following section, results and discussion are mainly related to those prototype 4 and 5.

III. RESULTS AND DISCUSSION

3.1 Workablity of prototype 4 and 5

In using a high clearance vehicle, it became possible to work in the field until the heading time of rice. The depth the machine sank in the soil was about 20cm during the crop growing period, and there was no pushing down of paddy stalk, except causing wheel marks on the ground. Owing to the setting the spreading nozzle in front of the vehicle, one–man–operation able to observe the spreading of seeds was enabled. In the direct sowing method, it is important to watch the spreading width and to observe the seed distribution, because there is no way to check them after the operation has done.

The seed supplying valve was replaced with a rotary type. This rotary valve has two rotors (110 $\phi \times$ 40mm) with 8 rubber vanes for each. With this valve, material supplying rate of 2 ～ 15kg/min was possible by regulating the motor speed (20 ～ 80rpm). The maximum supplying rate was 15kg/min in the case of granular fertilizer, and it became clear through experiments that this valve can also regulate the spreading rate from a larger grain such as coated seeds to smaller ones like granular herbicides.

The proportions of the nozzle used for spreading was a 2 meter long tapered pipe, with diameter at the outlet is 10cm. The velocity of compressed air at the outlet was about 80 ～ 100m/s under condition of 5500 rpm blower speed. Seeds were accelerated to the speed of 20 ～ 30m/s in the nozzle, and still propelled by the high speed air flow after leaving the nozzle. The seeds peak trajectory was 4 or 5 meters high. As the seeds fell from such heights, they were embedded into the proper depth of the soil, about 0.5 ～ 1.0cm. If the field is not drained well and some water still remains on the ground over 1cm deep, seeds will not be embedded properly due to the water absorbing the impact energy, and it may cause lodging later.

3.2 Field performance in sowing operation

Experimental cultivation using the super wide spreader was carried out at the experiment station for several years(Fig. 3). The area of the paddy field tested was 2 hectares (50 × 400m). Owing to the spreading width of 50 meters in the sowing operation, the spreader traveled once in the middle of the field with 0.3 ～ 0.5m/s velocity. Target sowing rate was about 40kg/ha of dry paddy weight without coated materials, and target number of establishment was 80 ～ 100 per m^2. In the case of those conditions above, the seeding operation should be completed within 45 minutes with two people including experimental investigation, data collection and checking the machine. Though, working time became 0.76 man·hours/ha (Table 1), it was possibly to say that the effective field capacity would be 0.38 hours/ha if the operation was done by one person. This field capacity is about 2 ～ 10 times more effective than other methods of direct sowing, and about 60 times more than that of conventional transplanting operations.

Field experiments for spreading fertilizers and other granular chemical materials were also carried out. The obtained operating width was about 25 meters, which is half of that of the coated seeds, due to the smaller size of materials. In spite of the necessity of round trip operation, the field capacity for one operation of top dressing or herbicides application became 0.22 ～ 0.44 hours/ha. This is because the operating speed was little higher than the sowing operation and it didn't need replenishing time due to the smaller size of materials.

3.3 Growth and yielding ability

If the proper speed of vehicle traveling and nozzle pivoting were selected for the sowing operation, an equally distributed establishment would be obtained. After several years of attempts, a reasonable distribution of establishment was obtained (Fig. 4), and proper adjustments were clarified. Establishment usually undergoes influences not only by seed distribution but also local soil conditions. Considering the difficulty of obtaining an absolute plain elevation level especially in a large sized field, establishments shown in Fig. 4 are effective enough for the cultivation. Yield components related to the number of establishment, which is obtained through verification tests in an actual farmer's field in Yamagata prefecture, are also shown in Table 2.

Annual yield components from the last 7 years, including the year of cold damage of 1993, are shown in Table 3. The average yield through these years was 5.32ton/ha. Even though there were differences of varieties, the obtained yield stood comparison with that of transplanting.

3.4 Evaluation of the super wide spreader

As the spread area appears to be in the shape of a fan, there will be some areas of remnant both in the corners and at the beginning of a normal rectangular shaped field. Thus, this technology is suitable for the large sized field or the larger cultivation altogether with contiguous fields. Without those conditions, some rectification sowing with small applicators is expected to be carried out.

The largest problem made clear was wind obstruction. According to the properties of material spread, the wind exerts a serious influence upon spreading accuracies. Spreading operations are expected to be carried out during a calm period in the morning or in the evening. When the velocity of the wind is over 3m/s, the trajectory angle of the spreading nozzle should be lower – less than 15 degrees – in order to avoid influences by the wind. Still under the condition of 6m/s wind, enough distribution could be obtained by carefully regulated operation and shifting the traveling path of the machine a particular distance toward the wind.

Another problems are bird damage, lodging and instability of establishment. These are related not only to the proposed method but also to another ways of direct sowing. It seems to be important to develop new varieties which have short culm and high lodging resistance, and to control measures to avoid lodging based on growth diagnosis which enables proper fertilizer applications. Many devices for bird prevention have been tried, but an enlargement of the area of direct sowing will certainly decrease bird damage.

IV. CONCLUSIONS

Through the development and experiments of the super wide spreader, the major conclusions were obtained as follows.

1) The proposed super wide spreader appeared to have high efficiency, and was suitable for the direct rice sowing cultivation in large sized paddy fields. The spreader could also handle fertilizers and other granular materials.

2) The reasonable distribution of establishment was obtained and yielding ability was high enough to stand comparison with that of conventional transplanting.

3) Wind conditions exert a serious influence upon the operating accuracy. The spreading operations are expected to be carried out at less than 6m/s wind.

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REFERENCES

1. Kimura,S. and S.Imazono. 1991. Development of labor saving operation technique for direct sowing rice cultivation coping with large divided field (part 1). Tohoku branch report of the JSAM 38: 15-18.

2. Kimura,S., S.Imazono and H.Takahashi. 1992. Development of labor saving operation technique for direct sowing rice cultivation coping with large divided field (part 3). Tohoku branch report of the JSAM 39: 55-58.

3. Kimura,S., T.Yamauchi, Y.Yaji and K.Motobayashi. 1994. Development of automatic straight traveling control system guided by laser-beam. Tohoku branch report of the JSAM 41: 61-64.

4. Kimura,S., Y.Yaji, T.Yamauchi and K.Motobayashi. 1995. Development of labor saving operation technique for direct sowing rice cultivation coping with large divided field (part 5). Tohoku branch report of the JSAM 42: 15-18.

5. Murakami,N., S.Imazono, and S.Kimura. 1991. Development of labor saving operation technique for direct sowing rice cultivation coping with large divided field (part 2). Tohoku branch report of the JSAM 38: 19-24.

6. Takahashi,H., S.Imazono, and S.Kimura. 1992. Development of labor saving operation technique for direct sowing rice cultivation coping with large divided field (part 4). Tohoku branch report of the JSAM 39: 59-62.

Table 1. Comparison between the working time of the proposed direct sowing cultivation and transplanting cultivation. (man·hour/ha)

	Experiment station	Surveyed farmers paddy field		Regional average
	direct sowing 1)	direct sowing 2)	trans-planting 3)	trans-planting 4)
Seed preparation	4.80	3.6	2.9	5.0
Seedling	—	—	44.2	53.0
Land preparation	7.90	6.8	15.9	29.0
Basal dressing	2.00	1.3	3.2	9.0
Sowing	0.76 *	1.5 *	—	—
Transplanting	—	—	24.2	44.0
Bird prevention	2.00	6.9	—	—
Top dressing	1.11 *	3.6 *	4.9	8.0
Herbicide application	1.11 *	2.2	1.1	12.0
Weeding	28.50	7.8	8.4	...
Water management	0.45 ****	15.4	22.9	59.0 ***
Diseases control	0.49 **	3.3	0.9	8.0
Harvesting and threshing	9.30	7.8	16.8	44.0
Drying and husking	14.22	45.5	27.7	25.0
Total	76.69	105.7	173.4	296.0

[Note] * The super wide spreader was used.
** The super wide spreader and other devices were used.
*** Includes weeding.
**** Automatic irrigation system was tested simultaneously.

Surveyed field

1) At Tohoku National Agricultural Experiment Station, Iwate pref. Japan, 2ha (50m×400m), 1994.
2) Farmer's field in Yamagata pref. Japan, 1.2ha (60m×200m), 1995. Values include traveling time between house and field.
3) Same farmer's as 2), total 4.8ha, 1994. Values include transportation time between the house and the fields.
4) Statistical data of farms over 5ha management in Tohoku region, 1992.

Table 2. Yield components related to the number of establishment

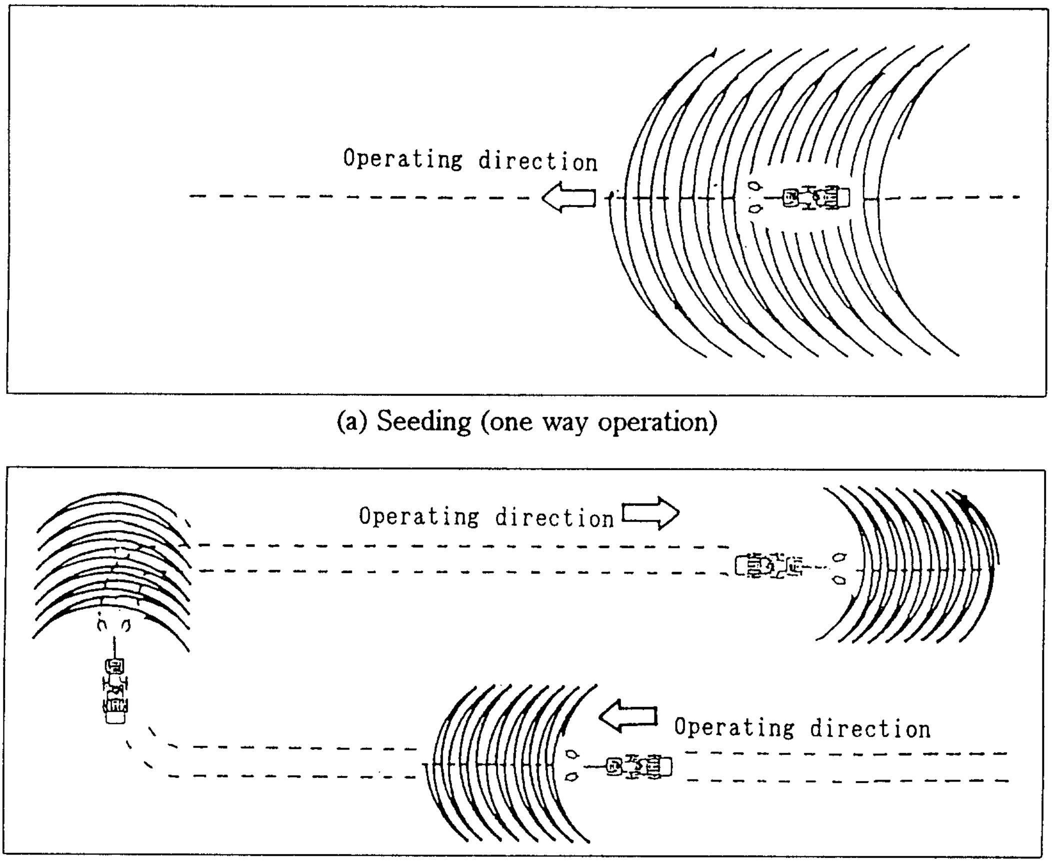
Establishment (No./m²) (Number of areas)	~40 (4)	40~60 (8)	60~80 (27)	80~100 (38)	100~120 (23)	120~ (20)	Average 98.0 (120)
Yield (g/m²)	356	419	456	445	436	420	437
Distribution	296~463	307~564	354~530	307~589	285~566	278~597	278~597
No. of heads (No./m²)	285	395	417	447	474	501	446
No. of stalks (No./m²)	28.5	54.0	66.7	83.8	99.3	149.3	90.0
Ear-stock ratio	10.9	7.3	6.3	5.4	4.8	3.6	5.5
No. of grains (No./head)	74.9	75.5	69.1	66.1	62.6	56.3	65.4
No. of grains (100/m²)	212	298	289	296	297	283	289
Ripened grains (%)	78.2	67.3	74.1	71.2	69.8	70.5	71.4
Sterile grains (%)	5.1	9.3	7.0	7.9	8.3	8.7	7.9
1000 grains weight (g)	22.5	21.6	21.9	21.7	21.7	21.7	21.8
Culm length (cm)	80.7	85.3	82.7	81.6	80.4	80.2	81.6
Degree of lodging (0~4)	0.0	1.4	2.4	2.7	3.1	3.5	2.7

[Note] Surveyed paddy field : 1.2ha(60m×200m), in Yamagata pref. Japan(1995)
Surveyed area : 120 points, each points is 1m².
All yields are measured as husked rice.

Table 3. Annual yield components

Year	1989	1990	1991	1992	1993 1)	1994	1995
Area (ha)	0.30	1.00	1.15	1.65	2.00	2.00	2.00
Variety of rice	Akita-komachi	Mutsu-homare	Mutsu-homare	Mutsu-homare	Yamauta	Yamauta	Maihime
Date of sowing	5/13	5/11	5/10	5/12	5/11	5/11	5/10
Sowing rate (kg/ha)	66	57	44	45	45	48	45
Establishment (No./m²)	96	104	135	74	88	77	151
Average temp. 2) (°C)	12.2	15.7	15.2	12.4	12.1	13.1	15.6
Date of heading	8/21	8/11	8/11	8/16	8/22	8/8	8/13
Accumlated temp. 3) (°C)	1944	1803	1772	1779	1793	1757	1768
Culm length (cm)	83.8	77.2	65.6	71.2	55.6	72.7	69.2
Head length (cm)	18.0	15.4	15.7	16.8	16.5	19.6	16.8
No. of heads (No./m²)	447	484	421	398	367	383	387
Yield (ton/ha)	4.88	6.34	5.53	5.83	3.80	5.51	4.74
(Cf.) Yield at transplanting	5.08	6.22	5.36	6.03	3.29	5.88	5.04
Direct-trans ratio	0.96	1.02	1.03	0.97	1.16	0.94	0.94

[Note] Surveyed field : Tohoku national agricultural experiment station, Japan
All yields are measured as husked rice.
1) 1993 is a year of cold damage.
2) Average temperature through 5 days within sowing day.
3) Accumlated temperature from sowing day to heading time.



(a) Seeding (one way operation)

(b) Chemical application (round trip operation)

Fig. 1 Operating methods with the super wide spreader.

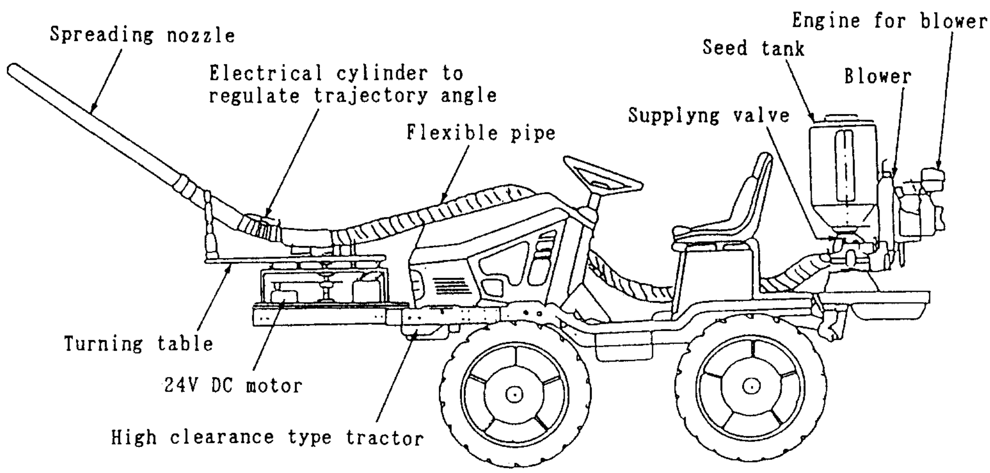


Fig. 2 Configulation of the prototype 5.

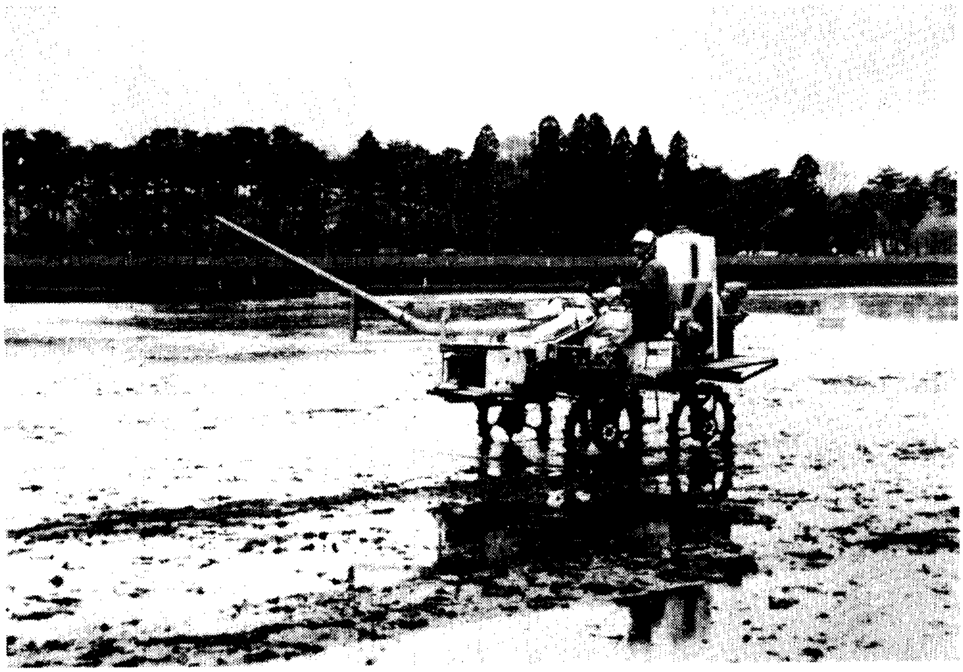


Fig. 3 Sowing appearance with the super wide spreader.

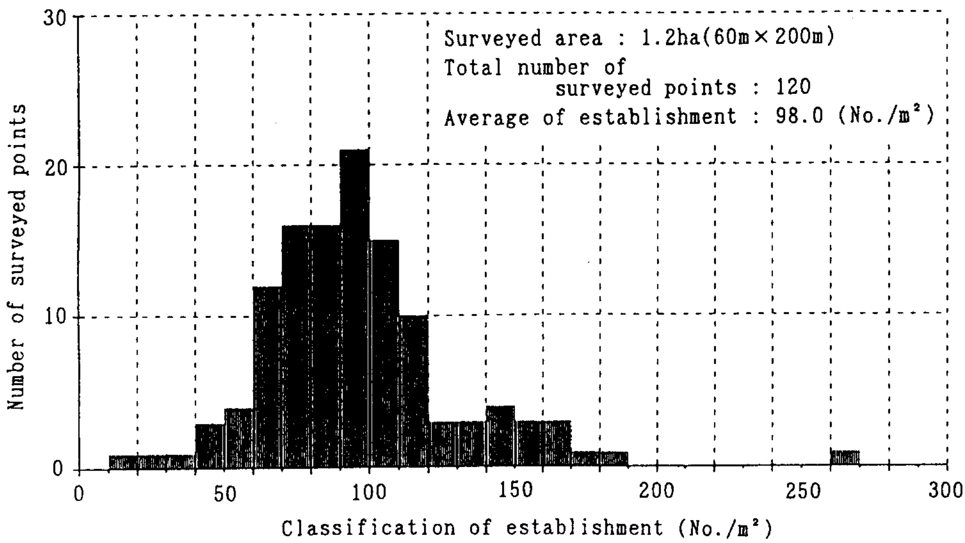


Fig. 4 Distributions of the establishment. (Yamagata,1995)