458

Airboat design and operational losses of a wild rice harvester

O. W. ARCHIBOLD[1] and W. B. REED[2]

epartment of Crop Science and Plant Ecology, University of Saskatchewan, Saskatoon, SK, Canada S7N 0W0; and [2]Department gricultural Engineering, University of Saskatchewan, Saskatoon, SK, Canada, S7N 0W0. Received 1 November 1988, accepted 19 September 1989.

hibold, O. W. and Reed, W. B. 1990. **Airboat design and operaal losses of a wild rice harvester.** Can. Agric. Eng. **32**: 69–74. Wild is grown in waterbodies across northern Saskatchewan and is hared by air-driven boats equipped with grain-collecting pans which disge the easily shattered kernels. The design of the harvesters is dissed and airflow characteristics measured. Wind speeds in excess of km/h were recorded behind a harvester. During turning manoeuvres air is directed laterally into unharvested rice by the rudders and some in loss occurs. Grain losses from wind blast during static trials was asured at 3.7%, while under normal operating procedures losses ranged n 4.7% adjacent to the hull to 1.2% at distances of 2.5 m.

INTRODUCTION

ld rice (*Zizania palustris* L.) is an emergent, aquatic cereal ive to eastern North America. It has long been a staple food Indians in the Great Lakes region and stands were established explorers as they travelled westwards by canoe. Commercial erest in the crop since the 1960s has led to extensive seeding many lakes and slow moving rivers across the southern boreal est region of Ontario, Manitoba and Saskatchewan and nadian production increased to 2 000 000 kg in 1987. In the ited States the leading producers are Minnesota (7 000 000 kg 1987) and California (13 000 000 kg in 1987), but there the p is grown in artificially flooded paddies.

Traditionally, the ripe kernels were harvested by canoe using d flails and this practice still continues in some reserve lands Canada and the United States (Winchell and Dahl 1984). Unlike ural stands, paddy wild rice varieties do not shatter readily. is permits the grain to be harvested with combines: which are ically track mounted to facilitate travel over the soft organic ls. Internal modifications of the cylinder and rasp bars are uired (Boedicker et al. 1984, 1985, 1986; Schertz et al. 1987). e majority of Canadian wild rice is harvested by airboat g. 1). Initially, these airboats were produced by individual owers in home workshops and the countless designs reflected th the ingenuity of the builder and the availability of materials. In Saskatchewan the government has actively encouraged the pansion of wild rice through seed grants and other incentives d several companies now construct airboats commercially. The est designs use aluminum hulls and air-cooled Rotax engines, t despite changing technology there has been little research into efficiency of the craft. This paper outlines preliminary experints that were conducted in the fall of 1987 to determine the iciency of various hulls and power plants.

AIRBOAT DESIGN

nadian wild rice harvesters consist of air-propeller-driven boats equipped with a grain-gathering device popularly known as a "speedhead". The most common boat design is a blunt bowed single hull approximately 4 m in length and 1.5 m in width. The header width (harvesting swath) varies from 2.5 m to 3 m, although headers up to 3.6 m are sometimes used. Two air rudders positioned behind the propeller are manually operated to steer the airboat. Aluminum is now used in construction, but many fiberglass hulls are still in use. Some growers have constructed larger pontoon harvesters. Their general design incorporates two long (6 m), narrow (0.6 m) pontoons spaced about 1.5 m apart. The pontoons are linked by engine supports at the rear, the operators platform in the centre and the header raising mechanism towards the front.

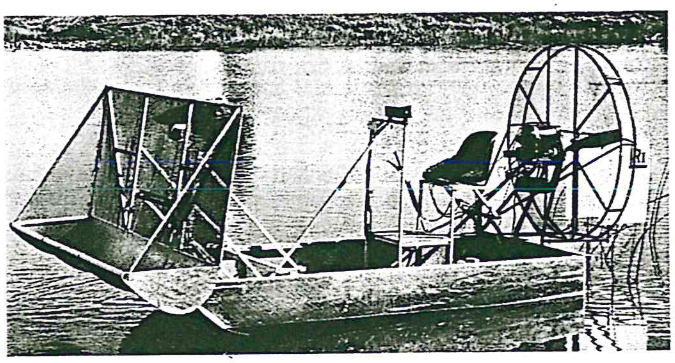

Fig. 1. A wild rice airboat typically consists of a propeller-driven, flat-bottomed hull. Ripe kernels are dislodged by the speedhead mounted across the front. The airboat pictured here is constructed of aluminum and is powered by a 503 Rotax engine.

The speedheads are constructed of a lightweight frame, a shallow tray at the bottom, and connecting members to the lifting mechanism mounted on the airboat. The rear of the speedhead frame is covered with window screening material, with the ends either solidly enclosed or partially covered with window screen. The speedhead is a passive device. There are no moving parts, although stationary "beater bars" added to the front of the speedhead may be positioned at the discretion of the operator. Harvesting is accomplished by the impact of the wild rice plants against the forward, lower edge of the header and the beater bars. The dislodged grain falls into the collection pan.

Wild rice grain matures from the top of the panicle downwards and the kernels shatter readily when ripe. A stand of wild rice is generally harvested 6–8 times over a 3-wk period. The airboats must therefore be operated carefully to avoid plant damage in order to maximize harvest yields.

The smaller flat-bottomed airboats are typically fitted with Rotax engines, Models 447 or 503. These are lightweight, 2-cycle, 2-cylinder, air-cooled engines. An integrally mounted gearbox with a reduction of 2.58:1 is used to drive the wooden propeller. The larger pontoon harvesters employ a variety of engines. Most are liquid-cooled 4-cycle, 4- or 6-cylinder automobile engines and typically range in size from 2.3 to 3.6 L. On the larger engines the propeller is mounted directly to the crankshaft, whereas the smaller engines are coupled to the propeller through a 2.36:1 belt reduction drive. Operating rpm for the Rotax engines is about 6500 compared to 4500 rpm for the automobile engines.

Operators have been concerned that the spreading air currents behind their airboats could be knocking some grain into the water. Tests were performed to determine the pattern of air movement in the wake of a harvester. The research was carried out in two stages. Initially, a grid of points was established on a disused, sandy airstrip and the wind patterns created by three types of airboat established. Second, actual seed loss from propeller blast was investigated under static conditions and during trials along a measured course.

METHODS

Wind speed patterns generated by three different airboats were established using a hot wire anemometer (Kurz Model 443-M-R Air Velocity Meter) positioned over a 2 × 2-m grid of points. A shield over the sensor permitted directional measurments to be taken. The data represent average air velocities for a 20-s period at each grid point. The airboats were left on their trailers in order to adjust them to general operating trim. When moving through the water the bow of the air boat rises and the propeller blast is angled down towards the water. Thus air velocity close to the boat was measured below the center line of the airblast. The airboat waterlines ranged from 0.75 to 1.0 m above ground; air velocity measurements were taken at 1 m above this imaginary water surface (approximately 2.0 m above ground) to correspond with the general height of mature wild rice kernels. The data were subsequently compiled on an HP 7475A plotter using "Surface II" programs.

In order to establish seed loss from air blast during stationary tests, a regular grid of floating collecting trays was set out in a mature, unharvested stand of wild rice. Each tray consisted of a plastic horticultural flat 50 × 28 × 4 cm deep; these were evenly spaced on a 250-cm × 30-cm styrofoam float at 130 cm between centers. Each row in the grid consisted of two floats (six trays) 1.3 m apart with 2.0 m between adjacent rows. The harvester used in this test was a 503 Rotax powered airboat as this is the most common design now in use in the region. The airboat was centered 2.5 m in front of the grid and kept stationary by metal poles held at the bow. The engine was operated at normal harvesting speed for a period of 15 s. At the end of this time the number of wild rice seeds blown into the trays was counted. The experiment was repeated at three locations within the wild rice stand.

Seed loss during normal harvester operation was monitored using a series of 10 floats (each supporting three collecting trays) set out in the mature wild rice stand over a distance of approximately 75 m. The trays were designed to collect the seed that might be knocked off by the harvester as it passed by. Close to the airboat, seed might be shattered by the speedhead, the hull and propeller blast; this seed would be collected in the first tray on each float which was centered approximately 1.2 m from the center line of the hull. The middle trays centered 2.0 m from the center line of the hull were passed over by the speedhead: seed collected here could come from plants disturbed by the speedhead, wave action or propeller blast. The outer trays (centered 3.0 m from the center line of the hull) on each float were beyond the end of the speedhead: seed collected here should come from plants disturbed by propeller blast, but some could be thrown by the speedhead. Three trials were made using the 503 Rotax powered airboat with 3-m speedhead running at 20 km/h.

RESULTS

Air velocity patterns

Fig. 2 shows the wind pattern generated by a 447 Rotax powered airboat fitted with a 58-inch (147-cm) 102-cm pitch propeller.

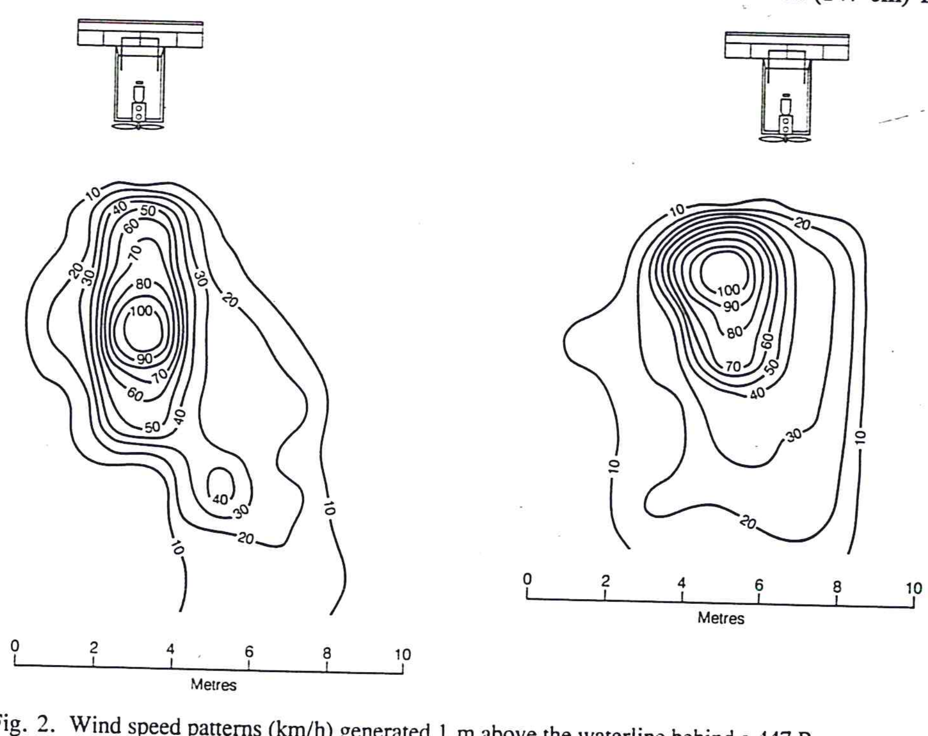

Fig. 2. Wind speed patterns (km/h) generated 1 m above the waterline behind a 447 Rotax powered airboat with straight rudder setting (left) and 45° left rudder setting (right). Estimated propeller speed is 2460 rpm. (The scale applies to both axes.)

During the test, engine rpm was maintained at the speed used for harvesting. With straight rudder setting, the zone of high speed air movement was generally restricted to a strip within the boundaries of the speedhead. At the time of the trial a cross wind gusting to 14.5 km/h was recorded. This could account for some of the displacement of the isotach pattern to the right. Air velocities increased from about 24 km/h at the edge of the zone passed over by the speedhead to over 100 km/h directly behind the propeller. Because of the inclined attitude of the airboat relative to the horizontal plane of measurement for air velocity, air-velocities increased rapidly about 1 m behind the airboat reaching a maximum at about 4.5 m. Beyond about 8 m the effect of propeller blast was negligible. A noticeable change in air velocity pattern occurred when 45° left rudder was applied. Although maximum air velocities were similar in both trials, the zone affected was considerably broader than the speedhead. On the left side of the airboat air velocities in excess of 32 km/h were recorded up to 1 m beyond the speedhead in a zone about 3 m behind the airboat. Air velocities subsided to ambient levels at a distance of 7 m behind the airboat in this simulated turning test.

The air velocity pattern generated by a 503 Rotax powered harvester is shown in Fig. 3. This airboat was fitted with a 159-cm propeller with a pitch of 102 cm. Maximum air velocities with the rudder straight reached 72 km/h at a distance of 3 m behind the airboat. Although the zone of high air velocity was generally confined to the width of the speedhead, air velocities above ambient levels were detected as much as 2 m beyond the edge of the table. As with the previous test, the displacement of the isotach pattern to the right of the airboat possibly resulted from the prevailing winds at the time of the trial. Also, a secondary peak in which air velocities reached 32 km/h was recorded behind the airboat during the straight rudder trial. This could represent turbulence created by the helical flow of air moved by the propeller. This secondary peak lies beyond the edge of the speedhead and could result in some grain loss during harvesting. With 45° left rudder maximum air velocities dropped to 56 km/h. However, this was recorded near the end of the speedhead and air velocities ranging from 16 to 48 km/h were noted up to 2 m beyond the speedhead for a distance of 6 m behind the airboat. The isotach pattern created during a turn is rather more elongated than that recorded during the Rotax 447 airboat turning trial. This is thought to result from the half rudders fitted to the Rotax 503 model airboat. Significant seed loss could be expected during turning or if excessive rudder movement is needed to keep the airboat on a straight course through the stand.

The third airboat tested was powered by a 1600 cc Ford automobile engine fitted with a 193 cm long, 51 cm pitch propeller and operated at 4500 rpm (Fig. 4). Maximum air velocities of 88 km/h were noted directly behind the propeller. Despite its extensive length the air blast zone was more or less confined to the width of the speedhead. During the turn trial 3/4 left rudder was applied. The effect was to displace the air well beyond the limits of the speedhead. Maximum air velocities exceeded 48 km/h about 1 m from the end of the table with speeds in excess of 20 km/h up to 3.5 m into the unharvested zone. The results suggest that grain losses should be minimal along straight passes providing little rudder movement is required to keep the airboat on course, but during turning operations substantial losses might occur.

Seed loss during stationary trials

In Trial 1 maximum seed loss was 100 seeds m^{-2}. This was within the zone which would be covered by the speedhead during normal harvesting. However, as many as 60 seeds m^{-2} were shattered beyond that traverse path. The zone of maximum seed loss was about 5.5 m behind the airboat where wind speeds were previously measured at 35–40 km/h. In the second trial, the zone of maximum seed loss occurred at a distance of 8.5 m behind the airboat with as many as 60 seeds m^{-2} falling into trays: this was within the secondary peak wind speed zone where velocities again reached 40 km/h (see Fig. 3). Seed losses in trial 3 were considerably lower than in the previous trial with

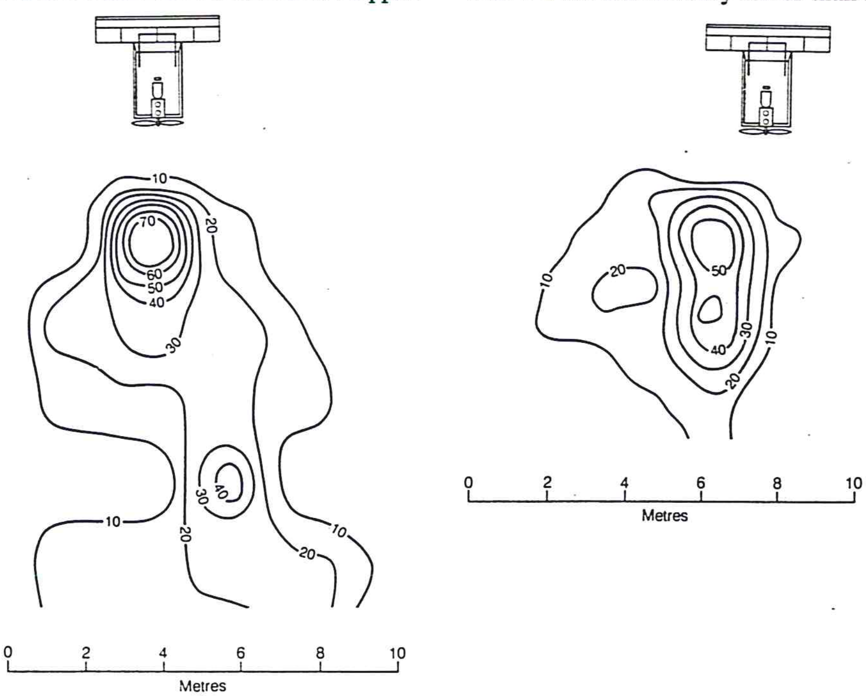

Fig. 3. Wind speed patterns (km/h) generated 1 m above the waterline behind a 503 Rotax powered airboat with straight rudder setting (left) and 45° left rudder setting (right). Estimated propeller speed is 4200 rpm. (The scale applies to both axes.)

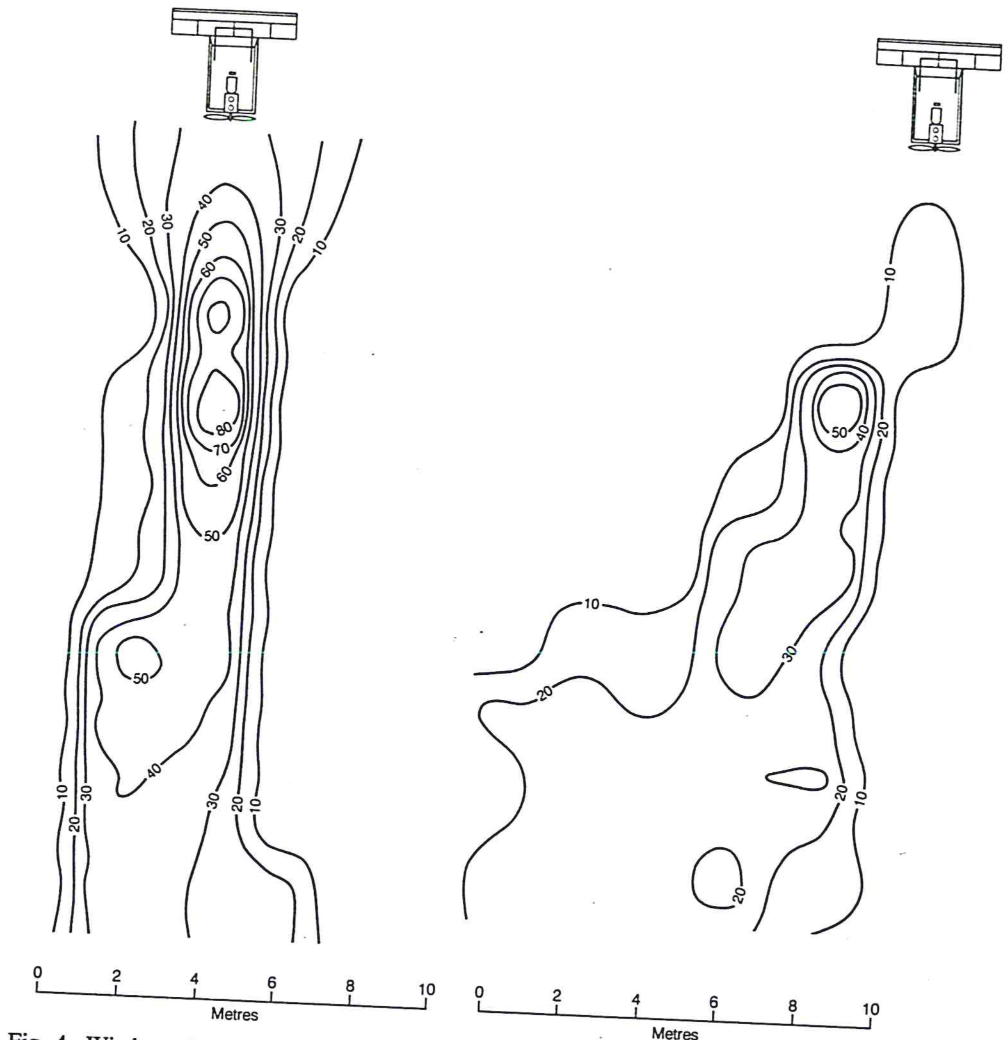

Fig. 4. Wind speed patterns (km/h) generated 1 m above the waterline behind a 1600 cc Ford powered airboat with straight rudder setting (left) and 3/4 left rudder setting (right). Engine speed is 4500 rpm. (The scale applies to both axes.)

a maximum shattering rate of 32 seeds m^{-2}. This occurred directly behind the airboat with a secondary peak of 16 seeds m^{-2} noted at 10.5 m. The variation in seed shattering rates noted in each of the trials could reflect differences in plant density and ripeness of seed. It was difficult to anchor the airboat securely in the deep, soft peaty sediment and slight differences in airboat attitude, engine speed, rudder movement etc. also could have affected the results. Figure 5 shows the average seed losses for the three trials. Within the zone covered by the speedhead seed losses ranged from 8 to 36 seeds m^{-2}. Maximum losses were recorded up to 5.5 m behind the airboat, but losses as high as 32 seeds m^{-2} were noted at 8.5 m. Both of these peak loss zones were related to wind speeds of 35–40 km/h. Beyond the speedhead losses as high as 24 seeds m^{-2} were recorded; maximum air velocity here was 20 km/h.

Seed loss during harvesting

The number of seeds shattered at varying distances from the hull of the passing airboat are listed in Table 1. Close to the airboat, where air velocities reached 70 km h^{-1} seed losses ranged from 44 to 62 seeds m^{-2} over the three trials. At 25 m from side of the hull, where air velocities exceeded km h^{-1}, seed loss ranged from 9 to 21 seeds m^{-2}: at a distance of 2.5 m, where air velocities were about 10 km hr^{-1}, losses were between 9 and 19 seeds m^{-2}. The variations in shattering losses recorded between runs could reflect differences in plant maturity and stand density. The crop is grown in unmanaged stands in remote areas of the province and considerable morphological variation occurs within and between sites (Archibold and Weichel 1986). Such variability makes replication of trials and estimates of error at one site difficult. In addition, variations in airboat speed, rudder movement or the relative heights of the speedhead and the mature flower heads between trials could also affect the results. However, a clear pattern of seed loss emerges when all of the data collected during the three trials are averaged (Fig. 6). The quantity of seed falling into the water decreases rapidly with distance from the hull. Changes in hull design could therefore be important in reducing harvest losses.

Stand conditions and relative harvest losses

Stem density in the trial patch averaged 148 stems m^{-2} (SD $\pm$ 34.3). Seed head characteristics, measured from a sample of 50 stems is shown in Fig. 7. Total floret numbers averaged 54.2 $\pm$ 20.8 per stem. Of these 8.6 $\pm$ 7.1 kernels (16%) were filled, 34.6 $\pm$ 20.2 kernels (64%) were not fully ripened, and 10.9 $\pm$ 13.9 (20%) had shattered in the three days between collection and analysis. Approximately 60% of these shattered

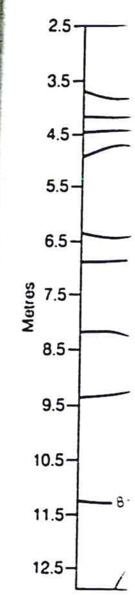

Fig. 5. Av
anchored 50
(The scale

Table I. Se

Run
1
2
3
Average

kernels we
hulls. Base
should pro
full, green
aged 8.6 k
could rang
average d
vest of ri
kernels m
Based on
kernel loss
from 4.7%
head and dr
Equivalent

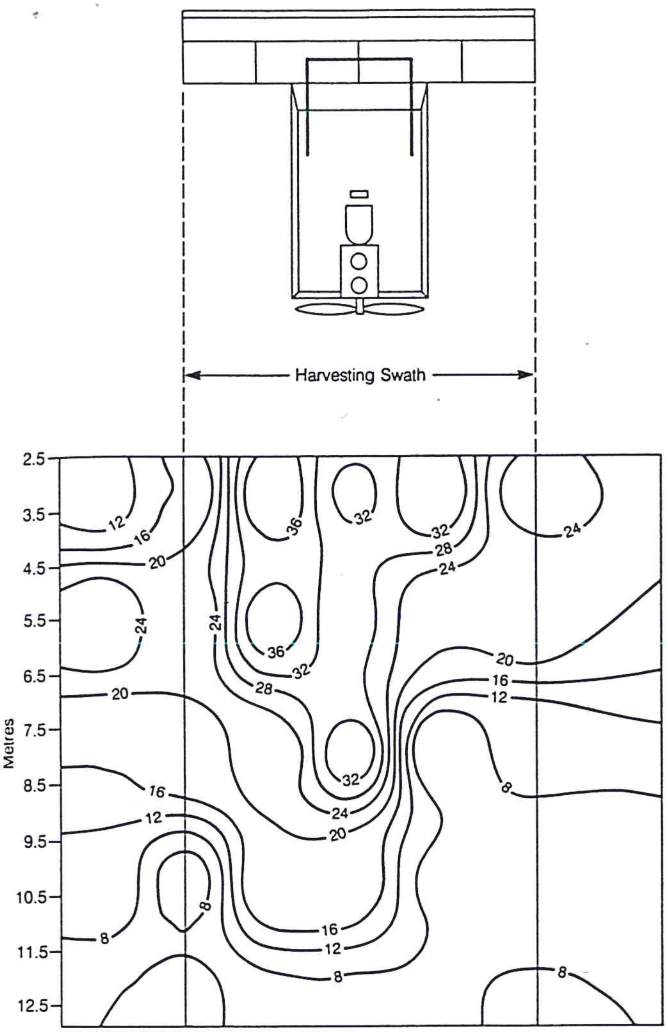

Fig. 5. Average seed loss (seeds m^{-2}) from propeller blast behind an anchored 503 Rotax powered airboat in an unharvested wild rice stand. (The scale applies to both axes.)

Table I. Seed loss (seeds m^{-2}) during airboat harvester operation

	Distance from hull (m)		
	0	1.25	2.5
Run			
1	62	21	9
2	35	9	9
3	44	18	19
Average	47	16	12

kernels were fully ripened; the remainder consisted of empty hulls. Based on these data it is estimated that the average stem should produce 6.6 kernels during the first harvest pass. Some full, green kernels would also be collected: Since these averaged 8.6 kernels $stem^{-1}$, harvest potential on the first pass could range from 6.6 kernels to 15.2 kernels $stem^{-1}$. With an average density of 148 stems m^{-2} this gives a potential harvest of ripe grain ranging from 977 kernels m^{-2} to 2250 kernels m^{-2}.

Based on a potential harvest of 977 kernels m^{-2}, average kernel loss during each harvest pass in the three trials ranged from 4.7% adjacent to the hull, 1.6% at the end of the speedhead and dropped to 1.2% beyond the harvester's path (Fig. 8). Equivalent losses at a potential harvest rate of 2250 kernels m^{-2} would be 2.1, 0.7 and 0.5%, respectively. Losses caused by propeller blast in unharvested stands would range from 3.7% (@977 kernels m^{-2}) to 1.6% (@2250 kernels m^{-2}) immediately behind the airboat.

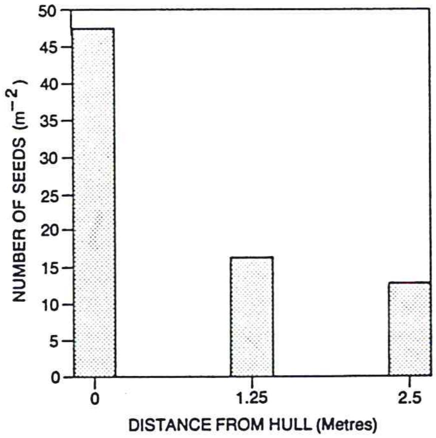

Fig. 6. Averge seed loss (seeds m^{-2}) at varying distances from the hull of a 503 Rotax powered airboat under normal operating conditions.

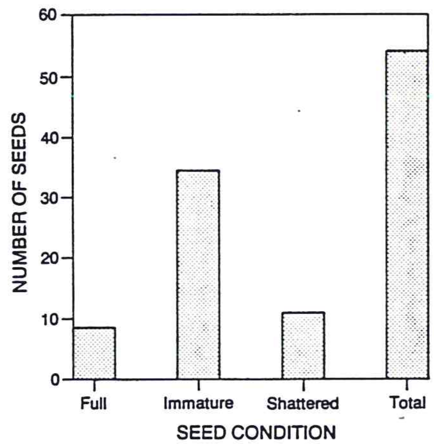

Fig. 7. Average seed head characteristics for wild rice plants in the stand used for the harvester trials.

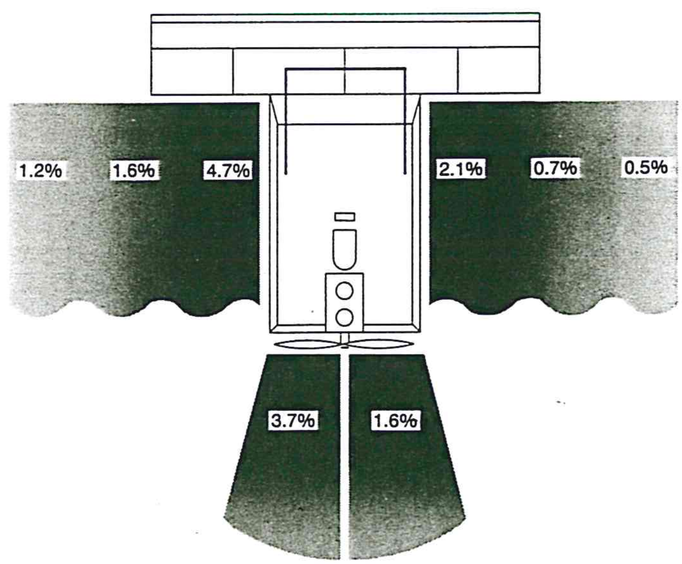

Fig. 8. Predicted maximum (left) and minimum (right) potential harvest losses during each pass of an airboat based on stand conditions during the harvester trials.

CONCLUSION

Considerable variation in airflow patterns occurred behind different types of harvesters with maximum air speeds exceeding 100 km/h. A loss rate of up to 3.7% was measured behind a 503 Rotax powered airboat in unharvested rice during the static test. Further losses were noted as the airboat passed through the stand. Close to the airboat seed, dislodged by the hull, by the speedhead and by propeller blast was equivalent to 4.7%, this decreased to 1.6% at 1.25 m from the hull and 1.2% at 2.5 m.

Air velocities in excess of 35–40 km/h resulted in extensive grain shattering. Velocities of this magnitude were measured at a distance of 8 m behind the 447 Rotax powered airboat compared to 5.5 m for the 503 Rotax powered craft, and both power units produced secondary peaks at approximately 9.5 m. Thus grain losses behind the smaller airboats may be higher than noted in the trials reported in this paper, particularly since these airboats are operated at full power in all but the lightest stands of wild rice. The custom-built Ford-powered airboat is characterized by an elongated airblast zone and higher grain losses are predicted: similar airboats used in wild rice stands in Idaho are fitted with deflectors which direct the air current upwards. Such a modification should be considered in future airboat designs.

Because wild rice is an aquatic crop, many unique logistical problems occured in carrying out this research. In particular, it should be noted that the initial air velocity measurements were recorded above a level sandy surface. Under normal operations the tall wild rice plants would likely dampen the air movement. Although this would not affect the initial high speed air blast on the crop, the "wind wake" would probably be shorter and narrower than noted in these trials. Further variation in the pattern might be expected if the forward motion of the airboat is taken into consideration. However, when in operation much of the air blast is directed onto the zone already passed over by the speedhead and losses of the easily shattered kernels here should be lower than measured in these trials. Only during turning manoeuvres would air blast contribute to significant crop loss.

ACKNOWLEDGMENTS

We wish to thank Mr. Kaz Parada of La Ronge Industries for providing the wild rice harvester used for most of these trials and for allowing access to the Potato Lake wild rice stand. Mr. Keith Bigelow of the Department of Geography, University of Saskatchewan completed the drafting. The research was through the Agriculture Development Fund, Saskatchewan Agriculture.

REFERENCES

ARCHIBOLD, O. W. and B. J. WEICHEL. 1986. Variation in wild rice (*Zizania plaustris*) stands across northern Saskatchewan. Can. J. Bot. 64: 1204–1211.

BOEDICKER, J. J., C. E. SCHERTZ, K. WICHETTAPONG, and M. C. LUEDERS. 1984. Combine harvest studies. Minnesota Wild Rice Research 1983, Agric. Exp. Station, University of Minnesota, St. Paul, MN. pp. 83–90.

BOEDICKER, J. J., C. E. SCHERTZ, K. WICHETTAPONG, and M. C. LUEDERS. 1985. Performance comparisons of spike tooth vs. raspbar cylinder and rotary vs. conventional combine. Minnesota Wild Rice Research 1984, Agric. Exp. Station, University of Minnesota, St. Paul MN. pp. 75–82.

BOEDICKER, J. J., C. E. SCHERTZ, K. WICHETTAPONG, and M. C. LUEDERS. 1986. Rotary combine performance evaluation and spike tooth/raspbar cylinder performance comparison. Minnesota Wild Rice Research 1985, Agric. Exp. Station, University of Minnesota, St. Paul MN. pp. 58–66.

SCHERTZ, C. E., J. J. BOEDICKER, and M. C. LUEDERS. 1987. Wild rice harvest investigations relating to combine adjustment for maximum harvest profitability and methods for estimating percent recovery. Minnesota Wild Rice Research 1986, Agric. Exp. Station, University of Minnesota, St. Paul, Mn. pp. 73–85.

WINCHELL, E. H. and R. P. DAHL. 1984. Wild rice production, prices, and marketing. Misc. Publ. 29, Agric. Exp. Station, University of Minnesota, St. Paul, MN. 35 p.