Project No. RL0388
February 1992
Prepared at Lethbridge

REDUCTION IN CROP YIELD DUE TO SPRAYER AND TRACTOR TIRE DAMAGE

Manager: R. P. Atkins
Project Engineer: R. C. Maze

REDUCTION IN CROP YIELD DUE TO SPRAYER AND TRACTOR TIRE DAMAGE

Table of Contents

Table of Contents
(Continued)

ABSTRACT

Turf, tandem walking beam, lugged sprayer tires and tractor tires cause crop damage during spraying. Sprayer and tractor tire effects on crop growth during spraying season were examined. Experiments using single and dual tires on tractors (single vs. dual tractor), single and tandem tires with tractor tires (single vs. tandem sprayer), and single, tandem and lugged (single, tandem and lugged sprayer) tires were examined. Soil factors, crop growth, tire slip and physical characteristics of transport systems were monitored and tabulated. Analysis of variance and statistical results were compiled from the data obtained and recommendations made. The later the spraying operation took place, the greater the amount of crop damage. The mass of the tank when increased from 1818 to 3637 L (400 to 800 gal) did not significantly affect the reduction in yield due to tire traffic. Mass on the tractor tires did not affect yield results. Sprayer tires alone and tractor tires alone had smaller percentages of crop reduction than when sprayer tires were run in tractor tracks. However, if sprayer tires were not run in the tractor tracks, the overall percentage of crop reduction was greater than the reduction if the sprayer tires were run in the tractor tracks. Single turf sprayer tires caused slightly less overall crop damage than the tandem walking beam assembly. No difference in yield was found when using single or dual tires on tractors.

INTRODUCTION

The object of this study was to determine the relative effects of sprayer and tractor tires on crops during spraying season. A secondary objective was to determine how changes in soil or crop conditions changed the degree of crop yield reduction due to transport system effects. At present, most chemical application systems require a large mass of water to be applied to the crop along with the chemical. Chemical, water and application systems used for crop spraying can weigh upwards of 700 kg (1540 lb). As a result of high soil contact pressures, crop damage occurs under tires of both sprayer transport systems and tractors. This study evaluates crop damage due to sprayer transport systems and tractor tires. Results obtained were analyzed and recommendations made by which crop damage can be reduced through alterations in sprayer application methods.

EXPERIMENT #1 - SINGLE VS. TANDEM SPRAYER TIRES

METHODS AND MATERIALS

The single vs. tandem sprayer experiment examined crop yield reduction caused by sprayer transport systems and tractor tires. The experiment used 1818 and 3637 litres (400 and 800 gal) of water in a 3773 L (830 gal) sprayer tank. Yield reduction was evaluated for three crop growth stages, 2-3 leaf, 5-6 leaf and tillering stage. Six combinations of wheel assemblies, including single turf sprayer tires, tandem walking beam sprayer tires, tractor tires pulling a sprayer tank with single turf tires and tractor tires pulling a sprayer tank with a tandem walking beam transport system were compared with a control sample area. Three replications of each test were done in a full factorial block design.

Duram Wheat was seeded for the tests. However, the test area had, in the previous year, been worked under due to a drought in the area. The previous year Hard Red Spring Wheat was seeded. Therefore, a crop yielding a 60 percent/40 percent mixture of Durham Wheat and Hard Red Spring Wheat, respectively, resulted. A John Deere 2950 tractor was used to pull a Flexi-coil Model S62 sprayer tank.

The John Deere 2950 tractor was a 16 speed, 85 horsepower, front-wheel assist diesel tractor. Goodyear Power Torque 13.6-28, 8 bias ply tractor drive wheels were mounted on the front of the tractor. The section width of the front tires were 34.5 cm (13.6 in) and their overall diameter was 131.1 cm (51.6 in). The drive wheels of the tractor were Goodyear Power Torque 18.4-38, 8-ply rated tires with a section width of 47.2 cm (18.6 in) and an overall diameter of 173.5 cm (68.3 in). The static weight of the tractor taken from Nebraska Tractor Test Number 1473 was 3311 kg (7080 lb) on the rear tires and 1370 kg (3020 lb) on the front tires.

Test plots were seeded and fertilized at a rate of 106 kg/ha (95 lb/ac) and 28 kg/ha (25 lb/ac), respectively. Seed and fertilizer application was done using a 11.9 m (39 ft) Flexi-coil prototype air drill with 18.29 cm (7.2 in) row spacing. Seed and fertilizer was placed into soil moisture at a depth of 7.62 cm (3 in) using hoe drill openers. Round steel packers were used to pack seed and fertilizer. An application of anhydrous ammonia fertilizer took place earlier in the year.

Single turf tires and tandem walking beam tire assemblies were used on the Flexi-coil sprayer tank. The turf tires were Goodyear 16.5L - 16.1, 6-ply, tubeless all-weather tires. A tire pressure of 165 kPa (23.9 psi) was used in the turf tire. The tandem tires were Goodyear 12.5L - 15, 8-ply, farm service nylon tires with a pressure of 193 kPa (28.0 psi). The tank had a maximum capacity of 3773 L (830 gal). The right and left side sprayer tank transport systems were mounted on independent, adjustable axle assemblies. The axles were adjustable so the distance between the left and right side transport systems on the sprayer tank could be altered. A three-point hitch drawbar was constructed and mounted on the tractor. The drawbar allowed the sprayer tank to be hitched at any point across the back of the tractor. The tank was hitched at a point behind the centre of the right tractor tire. The axle on the sprayer was adjusted so the left tires of the sprayer ran in the left tractor tire tracks. The right tires of the sprayer ran independent of the tractor tracks to the right side of the tractor. The track left by the right hand side of the tractor ran in the centre of the sprayer tracks. All sides were referenced from the back of the implements.

Granular Carbofuran insecticide was applied around the edge of the plot area to control the insect population. Two herbicide applications took place 21 and 35 days after seeding to control Russian and Canada Thistle. Since conventional spray would have altered test plot results, herbicide applications were contracted to local airplane spraying companies. The first application was 0.35 L/ha (5 oz/ac) of 2,4-D and 0.07 L/ha (1.0 oz/ac) of Dicamba. Due to the lack of weed control, an additional application of 0.07 L/ha (10 oz/ac) of 2,4-D and 0.07 L/ha (1 oz/ac) of Dicamba was applied.

Yield samples were taken using a Winter Stieger plot combine. A straight cut header was used to collect of sample area of 137 cm (54 in) over a distance of 76.2 m (250 ft). The plot combine was initially set on a trial plot. Once the combine was set it was not re-adjusted. Samples were collected in a cyclone. All samples were tagged and stored in 25 kg (55 lb) bags.

TEST PROCEDURES

Approximately 3.7 ha (10 ac) of a clay loam soil were used for the test. The test area, located 35 km (26 mi) southeast of Lethbridge, Alberta, was divided into 19.1 by 76.2 m (62.5 by 250.0 ft) strips. Each strip constituted seven test trials since both the single wheel, tandem wheel and control tests were completed on each plot area. For each wheel assembly configuration, tank mass and plant growth stage, three replications were made. Before each test was run, three soil samples were taken from the top 7 cm (2.8 in) of the trial strip about to be run over by the tractor and sprayer tank. A John Deere Model 2950 tractor was used for the tests. Once the sprayer wheel assembly was mounted on the tank and the hitch positioned so the left tank tires were running in the left tractor tracks, the tank was filled to the desired volume. Precautions were taken to ensure the diesel tank on the tractor was full before each trial was run to ensure the same tractor wheel soil contact pressures. Travel velocity was consistent through all tests at 8.1 km/h (5 mph). Slip measurements for the tractor tires were taken before each set of test trials, covering one plant growth stage for both 1818 L (400 gal) and 3637 L (800 gal) in the sprayer tank. For a given plant leaf stage and tank mass the tractor then pulled the tank through the three plots set out for that trial. The wheel assembly was then changed and the tank mass adjusted. The tractor again pulled the sprayer tank with the new wheel transport system through the same plot areas as the previous transport system tracks of the same tank mass and growth stage. After completion of all the trials for a particular plant stage, four trials with three replicates, the wheel tracks were staked at each end of their particular plots for future reference.

ANALYSIS PROCEDURE

A full factorial block design was used in the experiment. A total of 21 sample plot areas were set out in three blocks. Plot one was used to adjust combine settings. Each sample area contained all seven transport system effects for one tank mass and one crop growth stage. The amount of yield reduction for a particular plant growth stage, tank mass and wheel assembly was found by comparing yield samples in a plot area to a control sample in the same plot area. Samples, 104.4 m^2 (15625 ft^2), for each tank mass, growth stage and wheel assembly were obtained using a Winter Stieger plot combine. In all, 126 samples were taken over the entire test area. Samples were collected in a cyclone configuration on the plot combine and deposited into 25 kg (55 lb) bags. Sampling was completed over a two-day period. Once all the samples were collected, samples were run through a grain cleaner and weighed. Percentage of control yield was found by dividing the sample yield by the control yield in the plot the sample yield was obtained. Along with sample yield, soil moisture, tractor wheel slip, soil bulk density, plant growth stage and plant densities were recorded.

A factorial analysis was applied to the data using an analysis of variance or ANOVA table. The fixed effects of the ANOVA table, illustrated in TABLE 1, consisted of six transport effects (one control reference), three plant growth stages and two tank masses. The three blocks or replications were considered random effects nested within the fixed ANOVA format and therefore applied to the error term of the ANOVA.

TABLE 1. ANOVA Factors and Levels

FACTOR	LEVEL
TRANSPORT SYSTEMS (6)	**Single Sprayer Tires Single Sprayer Tire in Tractor Track Tractor Tire Pulling Single Sprayer**
Tires	**Tandem Sprayer Tires Tandem Sprayer Tire in Tractor Track Tractor Tire Pulling Tandem Sprayer**
Tires	**Control**
Plant Growth Stages (3)	**2 - 3 Leaf Stage 5 - 6 Leaf Stage Initial Tillering Leaf Stage**
Tank Mass (2)	**400 Gallons 800 Gallons**

The ANOVA table showed a statistical difference among the trial replicates at the 0.069 level of significance. Tank mass showed a significant effect at the 0.024 level of significance. Growth stage was highly significant at a level less then 0.005. The second order interaction between growth stage and tank mass showed a 0.033 level of significance. The ANOVA table is illustrated in TABLE 2.

TABLE 2. ANOVA Table Results

ANALYSIS OF VARIANCE OF 3-FACTOR TRANSPORT SYSTEM EXPERIMENT FOR A FULL FACTORIAL BLOCK DESIGN					
SOURCES OF VARIATION	**DEGREES OF FREEDOM**	**SUM OF SQUARES**	**MEAN SQUARE**	**F**	**P > F**
Treatments	**35**	**4723.05**	**134.94**	**1.2495**	**>0.10**
Blocks (b=3)	**2***	**616.78**	**308.39**	**2.8556**	**0.069**
Tires (w=6)	**5**	**206.96**	**41.39**	**0.3832**	**>0.10**
Tank Mass (M=2)	**1****	**577.46**	**577.46**	**5.3471**	**0.0243**
Growth Stage (G=3)	**2****	**1706.66**	**853.33**	**7.9016**	**<0.0050**
W & M	**5**	**177.65**	**35.53**	**0.3290**	**>0.10**
W & G	**10**	**622.65**	**62.26**	**0.5765**	**>0.10**
M & G	**2****	**793.96**	**396.98**	**3.6759**	**0.0325**
W & M & G	**10**	**637.70**	**63.77**	**0.5905**	**>0.10**
Error (R=3)	**70**	**7559.67**	**107.99**		
TOTAL	**107**	**12899.50**			

** Significant at 0.05 Level
* Significant at 0.01 Level

DISCUSSION

Soil Moisture

From soil moisture samples taken from the top 7 cm (2.76 in) of each test trial plot, an average percentage soil moisture content for each trial was found. Overall soil moisture on a dry weight basis during trials on the 1 - 2 leaf stage varied from 26.0 to 30.4%, with an overall average moisture of 28.3%. During the trial on the 4 - 5 leaf stage soil moisture varied from 27.5 to 31.4%, with an average of 29.2%. Trials in the tillering leaf stage varied from 14.2 to 16.7%, with an average of 15.7% total moisture on a dry weight basis.

Wheel Contact Pressures

Sprayer weights and wheel contact surface areas were obtained for no water, 1818 L (400 gal) of water and 3637 L (800 gal) of water in the sprayer tank. Tire weight was found by placing a scale under the desired measurement area and levelling the rest of the tank. Contact areas were calculated by levelling the sprayer tank and painting the tire surface to be examined. By lowering the painted tire surface onto a paper sheet, an imprint of the contact area was made. Since soil was considered an elastic deformable medium, an ellipse was constructed around the imprint area on the sheet. Contact area was then found by calculating the area of the ellipse corresponding to the imprint area. Using the calculated elliptical area of the tire imprint, contact areas were calculated for all wheel types and tank masses. For single turf tires on the left side of the sprayer tank, referenced from the back of the tank, the average contact pressure of the tire varied from 128.17 kPa (18.59 psi) with an empty tank, 155.20 kPa (22.51 psi) with 1818 L (400 gal) of water, to 170.02 kPa (24.66 psi) for 3637 L (800 gal), or a full tank. For the single turf tire on the right side of the sprayer tank, the average contact pressure of the tire varied from 108.45 kPa (15.73 psi) with an empty tank, to 174.44 kPa (25.30 psi) with 1818 L (400 gal) of water, to 184.20 kPa (26.72 psi) with a full tank. For tandem tires the contact pressure was somewhat higher, but over a smaller area. The pressure on the left tandem tires varied from 164.92 kPa (23.92 psi) with no water, to 192.23 kPa (27.88 psi) with 1818 L (400 gal) of water, to 189.54 kPa (27.49 psi) with 3637 L (800 gal) of water in a full tank. Right side tandem tires varied from 168.44 kPa (24.43 psi) with no water in the tank, to 209.81 kPa (30.43 psi) with 1818 L (400 gal) in the tank, to 179.88 kPa (26.09 psi) with 3637 L (800 gal), or a full tank. For lugged tires, right side wheel contact pressure was 78.53 kPa (11.39 psi). Left side lugged wheel contact pressure was found to be 85.08 kPa (12.34 psi) with no water in the sprayer tank.

Plant Growth Stages

An average plant growth stage was found before the plant growth factor trial was completed. To determine the average plant growth stage 0.25 m^2 (387.5 in^2) sample plots were used. Plant number, height and leaf stage were recorded. In the first growth stage trials, 84 plants were sampled, with an average height of 10.62 cm (4.18 in) and an average leaf number of 2.23. For the 4 - 5 leaf growth stage, 115 plants were sampled, with an average height of 19.11 cm (7.53 in) and an average leaf number of 4.63. In the final growth stage, 114 plants were sampled, with an average height of 46.17 cm (18.18 in) and an average leaf number of 7.24.

Crop Analysis Plant Concentration

Duram Wheat was seeded at a rate of 106 kg/ha (95 lb/ac) into a clay soil. The previous year the test plot area contained a crop of Hard Red Spring Wheat. Due to the drought conditions that prevailed that year, the crop was plowed under. Thus, the test areas contained both Hard Red Spring Wheat and Duram Wheat plants. A crop analysis was completed to determine if the plant concentration was consistent over the entire plot area. Ten 0.25 m^2 (387.5 in^2) random samples were taken over the plot area. On average, 42.14% and 69.86% of the plants were Durham Wheat and Hard Red Spring Wheat, respectively. The coefficient of variation among the plant concentrations of the sample areas was found to be 14.74%. The coefficient of variation was well within an expected variation over any field and thus concluded to be acceptable.

Slip Measurements

Slip measurement was done for all tank masses before each growth stage trial was completed. Using ASAE Standard S209.5 of the Agricultural Tractor Test Code, percentage slip was calculated. Slip measurements were completed at a speed of 8.1 km/h (5 mph) and a soil moisture content representative of the trial plots.

The maximum slip encountered was 6.84%. The average slip measurement for the John Deere tractor pulling the sprayer tank filled with 1818 L (400 gal) of water was 1.72%. With 3637 L (800 gal) of water in the sprayer tank the tractor tires had an average slip of 2.52%.

Soil Type

A Bouyoucos method soil particle analysis for the test plots was completed, with the results illustrated in TABLE 3.

TABLE 3. Soil Particle Analysis

SAMPLE DEPTH	1ST RDG. HY.	TEMP	2ND RDG. HY.	TEMP	% SAND	% CLAY	% SILT	TEXTURAL
7 cm	36.0	72.0	20.5	72.4	39.0	30.0	3l.0	CL

Soil Bulk Density Measurements

A soil cone penetrometer which conformed to ASAE standard S313.2 was used to measure soil cone index. Calibration of the penetrometer was done using known masses and load cells. In general, soil cone index was dependent on existing soil moisture and did not vary a great deal among tire tracks.

RESULTS

Yield varied from a minimum of 73.47% to a maximum of 114.29% of the control. The average percentages of the control were 93.96%, 91.72% and 85.57% for the initial, middle and final growth stages, respectively. The average percentage yield of the control for the 1818 L (400 gal) in the sprayer tank was 87.90% and for 3637 L (800 gal) in the sprayer tank, 93.16%. Overall percentages of yield for the transport systems varied from a minimum of 88.98% of control for the single and tractor tires in the same track to a maximum of 93.24% of the control for the single sprayer wheel alone. Results of the tests are available in TABLE 4 and FIGURE 1.

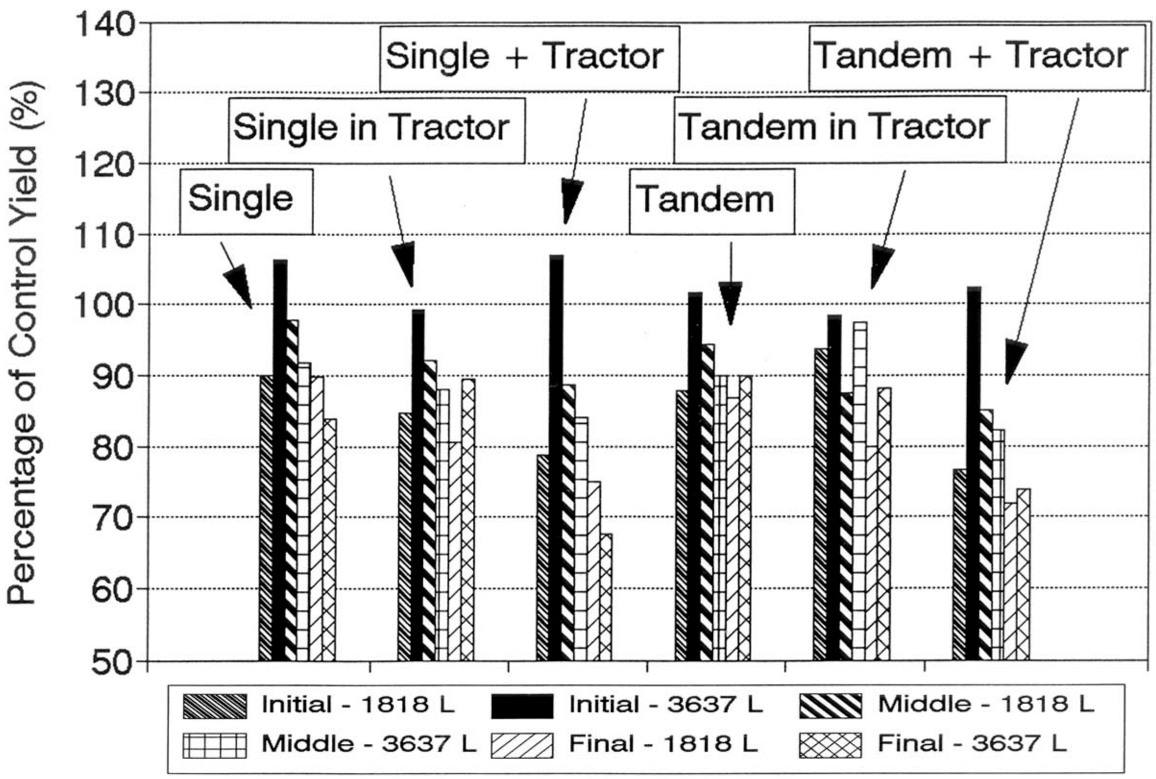

FIGURE 1. Single vs. Tandem Sprayer Tires.

TABLE 4. Percentage of Control Yields for Trials

WHEEL ASSEMBLY	GROWTH STAGE (LEAVES)	TANK MASS (LITRES)	PERCENTAGE OF CONTROL YIELD (%) BLOCK NUMBER 1	2	3
SINGLE	Initial (2 - 3)	1818 3637	73.47 99.77	83.18 109.66	113.20 109.48
	Middle (5 - 6)	1818 3637	82.90 99.52	104.56 87.53	106.00 88.25
	Final (Tillering)	1818 3637	92.54 99.14	87.21 75.14	89.46 77.33
TRACTOR-S	Initial (2 - 3)	1818 3637	88.91 87.39	78.70 77.95	89.04 110.04
	Middle (5 - 6)	1818 3637	81.46 100.25	100.88 82.67	104.24 93.46
	Final (Tillering)	1818 3637	90.89 94.49	79.51 75.47	88.47 90.11
SINGLE + TRACTOR	Initial (2 - 3)	1818 3637	83.66 99.09	80.18 96.22	90.09 102.13
	Middle (5 - 6)	1818 3637	78.52 96.90	95.31 75.01	102.66 92.30
	Final (Tillering)	1818 3637	85.69 94.22	76.36 81.58	79.34 92.37
TANDEM	Initial (2 - 3)	1818 3637	82.34 95.21	75.38 102.91	105.63 107.32
	Middle (5 - 6)	1818 3637	80.79 98.04	103.93 85.67	98.14 86.32
	Final (Tillering)	1818 3637	91.37 96.47	86.51 86.58	82.40 87.10
TRACTOR-T	Initial (2 - 3)	1818 3637	83.45 101.19	78.38 114.29	114.36 112.51
	Middle (5 - 6)	1818 3637	78.07 100.21	104.80 91.44	75.60 85.39
	Final (Tillering)	1818 3637	90.63 75.54	80.40 87.57	80.95 79.36
TANDEM + TRACTOR	Initial (2 - 3)	1818 3637	88.73 102.43	82.48 84.01	109.78 108.63
	Middle (5 - 6)	1818 3637	78.47 98.38	109.83 92.76	74.20 101.12
	Final (Tillering)	1818 3637	84.22 93.60	76.81 89.70	78.88 81.51

Transport System Effects

Six different transport configurations of the tractor tires and sprayer transport systems were used. One control sample was obtained for each plot. Ranking the transport systems in terms of least to highest reduction in crop yield, the single sprayer wheel performed the best, followed by the tandem sprayer tires. The tractor tracks by themselves caused approximately the same damage as the tandem and single sprayer tires running in the tractor tracks. The worst conditions occurred when the single sprayer tires ran in the tractor wheel tracks. Based on the results obtained in the ANOVA table, TABLE 2, transport systems provided a significant effect at the 0.01 level when the control was considered against the tires. However, no statistical difference was found if the control was not used in the ANOVA format.

Reduction in yield caused by a transport system is relatively small, approximately 3% for an 18.3 m (60 ft) spraying operation. TABLE 5 illustrates the reduction caused by an 18.3 m (60 ft) spraying operation using average values obtained in the test results.

TABLE 5. Yield Reduction of Sprayer Transport Systems for an 18.3 m (60 ft) Spraying Operation Using Overall Average Yield Reductions

WHEEL CONFIGURATION	CROP STAGE (%) REDUCTION			
	INITIAL (2-3 LEAF)	MIDDLE (5-6 LEAF)	FINAL (TILLERING)	AVERAGE
SINGLE SPRAYER TIRES	0.270	0.752	1.906	0.976
TANDEM SPRAYER TIRES	0.752	1.134	1.675	1.187
TANDEM SPRAYER TIRES IN TRACTOR TRACKS	0.577	1.089	2.294	1.320
TRACTOR TIRES (AVG)	0.768	1.222	2.246	1.412
SINGLE SPRAYER TIRES IN TRACTOR TRACKS	1.170	1.428	2.177	1.592
SINGLE SPRAYER TIRES + TRACTOR TIRES*	1.906	1.644	3.857	2.469
TANDEM SPRAYER TIRES + TRACTOR TIRES*	0.651	2.687	4.216	2.518

*Sprayers tires are not run in the track made by the tractor tires.

As illustrated in TABLE 5, sprayer and tractor tires alone have smaller percentages of crop reduction than when sprayer tires are run in tractor tracks. However, if sprayer tires are not run in the tractor tracks, the overall percentage crop reduction is greater than the reduction if the sprayer tires were run in the tractor tracks. The results obtained in these tests indicate spraying operations should take place with the sprayer wheel tracks running in the tractor tracks.

Comparing single turf sprayer tires caused an average yield of 93.24% of the control yield. Tandem walking beams caused slightly more crop damage overall, with an average yield of 91.78% of the control. This may be due to greater elliptical contact pressures of the tires.

Plant Growth Stage Effects

Three different plant growth stages were used for the test. When the crop was in the 2 - 3 leaf stage, tires caused an average 6.04% reduction compared to the control. The 5 - 6 leaf growth stage had a 8.28% reduction from the yield of the control plot. The highest reduction in yield occured in the final growth stage. Final growth stage had a yield reduction of 14.43% of control. The later the spraying operation took place, the greater the amount of crop damage which occurred.

Tank Mass Effects

Tank masses of 1818 L (400 gal) and 3637 L (800 gal) were used and the corresponding crop yield reductions evaluated. Overall, 1818 L (400 gal) reduced the sample yield by 12.09% from the control yield. The 3637 L (800 gal) caused a reduction of 6.84%. A large mass in the sprayer tank caused less of a reduction in total yield. This could be attributed to the increased contact area of the tires with the additional tank mass. As the tank mass increased from 1818 to 3637 L (400 to 800 gal) there was not an appreciable increase overall in the contact pressure of the tires.

From the ANOVA table analysis, TABLE 2, tank mass did not significantly effect the results.

EXPERIMENT #2 - SINGLE VS. DUAL TRACTOR TIRES

METHODS AND MATERIALS

The single vs. dual tractor tire experiment compared crop damage of single and dual tractor tires under four different loads and two crop growth stages. Crop stages were 2 - 3 leaf and initial tillering. For the single tire, the loads were 5340 kg (11770 lb), 5900 kg (13000 lb), 7200 kg (15870 lb) and 8530 kg (18810 lb). The dual tractor had loads of 5740 kg (12640 lb), 6290 kg (13860 lb), 7590 kg (16740 lb) and 8910 kg (19640 lb). Three replications of each test were done in a full factorial block design.

Single and dual tire were used on the John Deere 4440 tractor. The John Deere 4440 tractor was an 8 speed, 130 horsepower diesel tractor. From Nebraska Tractor Test Number 1357, the static weight of the tractor without ballast was 9470 lb (4296 kg) on the rear tires and 3650 lb (1656 kg) on the front tires. The tractor was fitted with Goodyear Dyna Torque (6 ply) 18.4-38 tires as singles. The section width of the Goodyear Dyna Torque tires was 47.2 cm (18.6 in), with an overall diameter of 172.7 cm (68.0 in). Kelly Springfield Power Mach 18.4-38 tires were used for the tractor duals. The 6-ply Kelly Springfield Power Mach tires had a section width of 47.2 cm (18.6 in) and an overall diameter of 173.5 cm (68.3 in).

Test plots were seeded with Ketepwa Spring Wheat at a rate of 101 kg/ha (90 lb/ac). The fertilizer 23-23-0 was applied at a rate of 84 kg/ha (75 lb/ac). Seed and fertilizer application was done using a 4.6 m (15 ft) John Deere Model 752 All-Till drill with 17.8 cm (7 in) row spacing. Seed and fertilizer were placed into existing soil moisture at a depth of 7.62 cm (3 in) using hoe drill openers. Round steel packers were used to pack seed and fertilizer.

A three-point hitch frame was constructed and mounted on the tractor. A 1360 L (300 gal) water tank was mounted on the three-point hitch frame. Changing the volume of water in the tank allowed the mass on the tires to be changed.

A herbicide application took place 20 days after seeding. A 6.4 m (21 ft) truck-mounted sprayer was used for herbicide application. The truck was driven between plot areas and did not interfere with the plots. The herbicide application consisted of an 84 g/l Dicamba and a 336 g/l MCPA-k mixture applied at 510 mL/ac and a water rate of 45 L/ac.

Yield samples were taken using a modified Case 960 plot combine. A straight cut header was used to collect a sample area of 4.3 m (14 ft) over a distance of 38.1 m (125 ft). The plot combine was initially set on a trial plot and not adjusted over the entire test area. Samples were collected in a weighing bin and mass measurements were taken using a load cell.

TEST PROCEDURES

Approximately 3.2 ha (8 ac) of clay loam soil were used for the test. The test area, located east of Lethbridge, Alberta, was divided into 6.4 m by 38.1 m (21 by 125 ft) strips. Each strip constituted one trial consisting of a wheel type, growth stage, wheel mass and replication. For each wheel assembly configuration, tank mass and plant growth stage, three replications were made. Before each test was run, three soil samples were taken from the top 7 cm (2.8 in) of the trial strip. A John Deere Model 4440 tractor was used for each trial. Different tank masses were obtained by changing the volume of water in the tank. Precautions were taken so the diesel tank on the tractor was full before each trial was run to ensure the same tractor wheel soil contact pressures. Travel velocity was consistent through all tests at 8.1 km/h (5 mph). Slip measurements for the tractor tires were taken before each set of test trials encompassing one plant growth stage, wheel type, and tank mass. Plant growth stage was also determined prior to testing. Once all the trials with the single tires were done, the duals were mounted and the trials repeated.

ANALYSIS PROCEDURE

A full factorial block design was used in the experiment. A total of 16 sample plot areas were set out in three blocks, with 48 plots in total. Each plot contained a specific wheel type, growth stage and tank mass. The amount of yield for a particular plant growth stage, tank mass and wheel assembly was determined. Samples of 162.6 m^2 (1750 ft^2) for each tank mass, growth stage and tire type were obtained using a modified Case 960 combine. In all, 48 samples were taken over the entire test area. Samples were collected in a hopper on the plot combine fitted with load cells. Sampling was completed over a 10 hour period. Along with sample yield, soil moisture, tractor wheel slip and plant growth stage were recorded.

A factorial analysis was applied to the data using an analysis of variance or ANOVA table. The fixed effects of the ANOVA table, illustrated in TABLE 6, consisted of two wheel types, two plant growth stages and four tank masses. The three blocks or replications were considered random effects nested within the fixed ANOVA format and therefore applied to the error term of the ANOVA.

TABLE 6. ANOVA Factors and Levels

FACTOR	LEVEL
Tire Type (2)	Single Tractor Tires Dual Tractor Tires
Plant Growth Stages (2)	Initial (2 - 3) Leaf Stage Final (Tillering) Stage
Tank Mass (4)	Zero Single: 5340 kg Dual: 5740 kg Hitch Single: 5900 kg Dual: 6290 kg 1/2 Full Single: 7200 kg Dual: 7590 kg Full Single: 8530 kg Dual: 8910 kg

The ANOVA table showed a highly significant statistical difference among the trial blocks at the 0.0078 level of significance. Growth stage was significant at the 0.0775 level of significance. The second order interaction between tire type and tank mass showed a 0.0213 level of significance. The ANOVA table is illustrated in TABLE 7.

TABLE 7. ANOVA Table Results

ANALYSIS OF VARIANCE OF 3-FACTOR TRANSPORT SYSTEM EXPERIMENT FOR A FULL FACTORIAL BLOCK DESIGN					
SOURCES OF VARIATION	**DEGREES OF FREEDOM**	**SUM OF SQUARES**	**MEAN SQUARE**	**F**	**P > F**
Treatments	15	1933.15	128.88	1.7380	>0.10
Blocks (b=3)	2**	860.79	430.40	5.8043	0.0078
Tire Type (T=2)	1	50.02	50.02	0.6746	>0.10
Tank Mass (M=4)	3	244.40	81.47	1.0986	>0.10
Growth Stage (G=2)	1*	256.69	256.69	3.4617	<0.0775
T & G	1	2.52	2.52	0.0340	>0.10
T & M	3**	848.90	282.97	3.8160	0.0213
M & G	3	356.90	118.97	1.6044	>0.10
T & M & G	3	173.73	57.91	0.7810	>0.10
Error (R=3)	70	7559.67	107.99		
TOTAL	47	5018.48	106.78		

** Significant at 0.05 Level
* Significant at 0.01 Level

DISCUSSION

Soil Moisture

From soil moisture samples taken from the top 7 cm (2.8 in) of each test trial plot, an average percentage soil moisture content for each trial was found. Soil moisture on a dry weight basis during trials on the 1 - 2 leaf stage varied from 15.65 to 20.70%, with an overall average moisture of 18.90%. Trials in the initial tillering leaf stage varied from 9.54 to 11.62%, with an average of 10.43% total moisture on a dry weight basis.

Wheel Contact Pressures

Four different weights were used to apply varying pressures to the wheel masses on the single and dual tractor tires. For the single tractor tires the weights of the back tractor tires were 5340, 5900, 7200 and 8530 kg (11770, 13000, 15870 and 18810 lbs). For the dual tractor tires the wheel weights were 5740, 6290, 7590 and 8910 kg (12640, 13860, 16740 and 19640 lbs).

Plant Growth Stages

Since the same field was used for Experiments 2 and 3, leaf counts and lengths were done at the same time. Plant leaf counts and leaf lengths were taken for the initial and final plant growth stages. Approximately 100 samples were taken for each growth stage. For the initial growth stage, an average of 2.38 leaves, with an average length of 13.7 cm (5.4 in) were used. A 23.5% coefficient of variation was found for the leaf count in the initial growth stage. For the final growth stage an average of 3.82 leaves were found, with a coefficient of variation of 11.87%. The average leaf length was 26.7 cm (10.51 in) with an 18.41% coefficient of variation.

Slip Measurements

Slip measurement were done for all tank masses before each growth stage trial was completed. Using ASAE Standard S209.5 of the Agricultural Tractor Test Code, percentage slip was calculated. Slip measurements were completed at a speed of 8.1 km/h (5 mph) and a soil moisture content representative of the trial plots.

The maximum slip of the single vs. dual tractor tire experiment was 3.19%, which occurred with no added weight on the tractor tires and dual tires. Average slip for single tires with the different weights was 1.49%. Average slip for the dual tires with the different weights was 2.26%.

Soil Type

A Bouyoucos method soil particle analysis for the test plots included in Experiments 2 and 3 was completed, with results illustrated in TABLE 8.

TABLE 8. Soil Particle Analysis

SAMPLE DEPTH	1ST RDG. HY.	TEMP	2ND RDG. HY.	TEMP	% SAND	% CLAY	% SILT	TEXTURAL
7 cm	36.0	73.9	21.5	72.8	38.0	33.0	29.0	CL

RESULTS

Crop yield results for the single vs. dual tractor tire experiment varied from 16.8 to 37.2 kg (37.0 to 82.0 lb). The single tractor tires yielded an overall average of 29.1 kg (64.2 lb). The dual tractor tires' average yield was 30.1 kg (66.3 lb). In general, increasing weight on the single and dual tractor tires caused a decrease in yield. From no added weight to maximum added weight the yield was 30.4, 30.7, 28.9 and 28.3 kg (67.1, 67.8, 63.8 and 62.3 lb), respectively. Average yields for the initial and final growth stages were 30.6 and 28.5 kg (67.5 and 62.9 lb), respectiviely. Results are located in TABLE 9 and illustrated in FIGURE 2.

TABLE 9. Yields for Single vs. Dual Tractor Trials

TIRE TYPE	GROWTH STAGE (LEAVES)	TANK MASS (lbs)	YIELD kg (lbs) BLOCK NUMBER 1	2	3
SINGLE	INITIAL (2 - 3)	ZERO	29.0 (64.0)	37.2 (82.0)	31.8 (70.0)
		HITCH	31.8 (70.0)	32.7 (72.0)	31.8 (70.0)
		1/2 FULL	29.9 (66.0)	36.3 (80.0)	26.8 (59.0)
		FULL	20.9 (46.0)	28.1 (62.0)	27.2 (60.0)
SINGLE	FINAL (Tillering)	ZERO	34.9 (77.0)	32.2 (71.0)	30.4 (67.0)
		HITCH	26.3 (58.0)	34.0 (75.0)	29.5 (65.0)
		1/2 FULL	16.8 (37.0)	25.4 (56.0)	30.8 (68.0)
		FULL	17.7 (39.0)	26.8 (59.0)	30.8 (68.0)
DUAL	INITIAL (2 - 3)	ZERO	19.5 (43.0)	33.6 (74.0)	33.1 (73.0)
		HITCH	20.0 (44.0)	34.5 (76.0)	32.2 (71.0)
		1/2 FULL	35.4 (78.0)	33.1 (73.0)	29.9 (66.0)
		FULL	30.8 (68.0)	34.0 (75.0)	35.8 (79.0)
DUAL	FINAL (Tillering)	ZERO	27.2 (60.0)	28.1 (62.0)	28.1 (62.0)
		HITCH	34.0 (75.0)	30.8 (68.0)	31.3 (69.0)
		1/2 FULL	28.6 (63.0)	25.9 (57.0)	28.1 (62.0)
		FULL	28.1 (62.0)	29.9 (66.0)	29.0 (64.0)

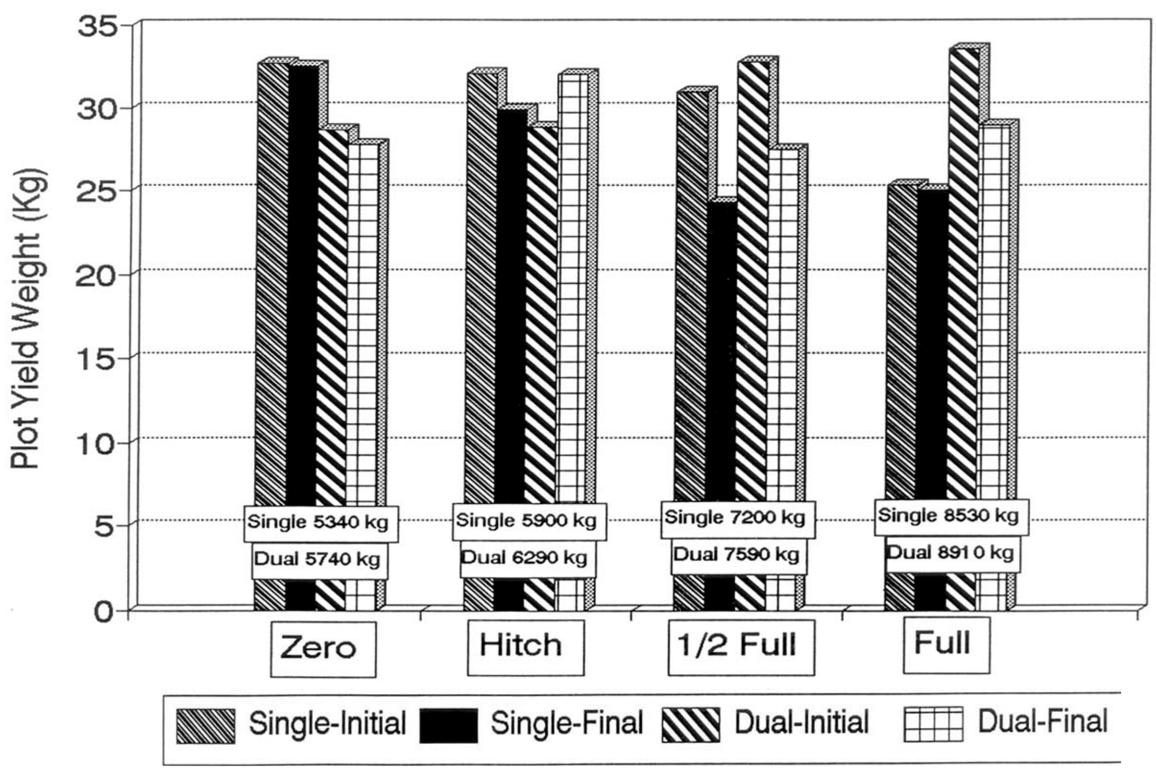

FIGURE 2. Single vs. Dual Tractor Tires

Transport System Effects

Two different transport configurations of the tractor tires were used. No apparent trend resulted from single and dual tractor tire experiment in terms of crop yield. Based on the results obtained in the ANOVA table, TABLE 7, tractor tires provided no significant effect in the yield results at the 0.01 level.

Plant Growth Stage Effects

Two different plant growth stages were used. The ANOVA results indicated a significant difference at the 0.0775 level. When the crop was in the 2 - 3 leaf stage, the crop yielded an average of 30.6 kg (67.5 lb). When the tractor tire ran over the crop in the final growth stage the crop yielded an average of 28.5 kg (62.9 lb). In all cases, except with the dual wheels at 6290 kg (13860 lb), the later the crop stage, the less the yield.

Tank Mass Effects

Four tank masses were used and corresponding crop yield evaluated. ANOVA results indicated no significant difference in the yield results caused by the different tank masses. No trends were apparent from the results.

EXPERIMENT #3 - SINGLE/TANDEM/LUGGED SPRAYER TIRES

METHODS AND MATERIALS

The single/tandem/lugged sprayer experiment examined crop yield reduction caused by sprayer transport systems. Three tire types, single, tandem and lugged and one control were used with a tank containing 3637 L (800 gal) of water. Two growth stages, 2 - 3 leaf and tillering, were examined. Three replications of each trial were done in a full factorial block design.

Plots were seeded using the same rates and equipment as the single vs. dual tractor tests (Experiment 2). The same herbicide application as on the single vs. dual tractor plot took place.

Single turf tires, a tandem walking beam tire assembly and lugged tires were used on the Flexi-coil sprayer tank. The turf tires were Goodyear 16.5L - 16.1, 6-ply, tubeless all-weather tires. A tire pressure of 165 kPa was used in the turf tire. The tandem tires were Goodyear 12.5L - 15, 8-ply, farm service nylon tires with a pressure of 193 kPa. The lugged tires were Goodyear 18.4 - 16.1 6-ply tires with a pressure of 14 psi. The tank had a maximum capacity of 3773 L (830 gal) and was filled for each test. The right and left side sprayer tank transport systems were mounted on independent, adjustable axle assemblies. The axles were adjustable so the distance between the left and right side transport systems on the sprayer tank could be altered. A three- point hitch drawbar was constructed and mounted on the tractor. The three-point hitch allowed the sprayer tank to be hitched at any point across the back of the tractor. For the tests, the tank was hitched at a point to the far right, to the outside of the right tractor tire. The axle on the sprayer was adjusted so the right tires of the sprayer were 6 feet from the right tractor tire. All sides were referenced from the back of the implements.

Yield samples were taken using a Modified Case 960 plot combine. A straight cut header was used to collect a sample area of 183 cm (6 ft) over a distance of 38.1 m (125 ft). The plot combine was initially set on a trial plot and not adjusted over the entire test area. Samples were collected in a weighing bin and mass measurements were taken using a load cell.

TEST PROCEDURES

Approximately 1.62 ha (4 ac) of a clay loam soil were used for the test. The test area, located east of Lethbridge, Alberta, was divided into 6.4 by 38.1 m (21 by 125 ft) strips. Each strip constituted one test trial, consisting of a particular wheel type and growth stage. A single sprayer tank mass was used for all trials. In all trials, 3637 L (800 gal) of water was used. For each wheel type and plant growth stage, three replications were made. Before each test was run, three soil samples were taken from the top 7 cm (2.8 in) of the trial strip about to be run over by the tractor and sprayer tank. A Massey Ferguson Model 3630 tractor was used for each trial. The sprayer wheel assembly was mounted on the tank and the hitch positioned so the right sprayer tank tires were running 183 cm (6 ft) from the right tractor tires. Travel velocity was consistent through all tests at 8.1 km/hr (5 mph). Slip measurements for the tractor tires were taken before each set of test trials encompassing one plant growth stage for 3637 L (800 gal) in the sprayer tank. For a given plant leaf stage and tire type, the tractor then pulled the tank through the three trial areas set out for that test. The wheel assembly was then changed and the test repeated on another plot area. After the completion of all the trials for a particular plant stage, three replicates were completed for each trial.

ANALYSIS PROCEDURE

A full factorial block design was used in the experiment. A total of 8 sample plot areas were set out in three blocks. Each sample area contained one tire type and growth stage. The amount of yield for a particular plant growth stage and tire type was determined using a modified Case 960 combine. Samples, 69.7 m^2 (750 ft^2), for each growth stage and tire type were obtained. Twenty-four samples were taken in the test area. Sampling was completed over a four hour period. Along with sample yield, soil moisture, tractor wheel slip and plant growth stage were recorded.

A factorial analysis was applied to the data using an anlaysis of variance or ANOVA table. The fixed effects of the ANOVA table, illustrated in TABLE 10, consisted of three wheel types with one control and two plant growth stages. The three blocks or replications were considered random effects nested within the fixed ANOVA format and therefore applied to the error term of the ANOVA.

TABLE 10. ANOVA Factors and Levels

FACTOR	LEVEL
WHEEL TYPES (4)	Single Sprayer Tires Tandem Sprayer Tires Lugged Sprayer Tires Control
PLANT GROWTH STAGES (2)	Initial (2 - 3) Leaf Stage Final (Tillering) Stage

The ANOVA table showed a statistical difference among the trial replicates at the 0.0489 level of significance. No other factors or interactions were significant at the 0.10 level of significance. The ANOVA table is illustrated in TABLE 11.

TABLE 11. ANOVA Table Results

ANALYSIS OF VARIANCE OF 3-FACTOR TRANSPORT SYSTEM EXPERIMENT FOR A FULL FACTORIAL BLOCK DESIGN					
SOURCES OF VARIATION	**DEGREES OF FREEDOM**	**SUM OF SQUARES**	**MEAN SQUARE**	**F**	**P > F**
Treatments	7	242.00	34.57	1.0227	>0.10
Blocks (B=3)	2**	256.08	128.04	3.7878	0.0489
Tires (W=4)	3	190.67	63.56	1.8801	>0.10
Growth Stage (G=2)	1	10.67	10.67	0.3155	>0.10
W & G	3	40.67	13.56	0.4010	>0.10
Error (R=3)	14	473.25	33.80		
TOTAL	23	971.33			

** Significant at 0.05 Level

DISCUSSION

Soil Moisture

From soil moisture samples taken from the top 7 cm (2.8 in) of each test trial plot, an average percentage soil moisture content for each trial was found. Overall soil moisture on a dry weight basis during trials on the 1 - 2 leaf stage varied from 16.00 to 20.30%, with an overall average moisture of 18.65%. Trials in the tillering leaf stage varied from 8.37 to 10.34%, with an average of 9.37% total moisture on a dry weight basis.

Wheel Contact Pressures

For Experiment #3 a lugged tire was used along with the turf and tandem tires used in Experiment #1. The Flexi-coil Model 62 sprayer tank was used with the lugged tires. With the tank empty the weight of the right lugged tire was 449 kg (990 lb), and the left tire, 440 kg (970 lb). With the 3637 L (800 gal) tank full of water the weight on the right lugged tire was 2190 kg (4830 lb) and on the left tire was 2200 kg (4850 lb). With the tank empty an elliptical area produced by the right tire was 560.6 cm^2 (86.9 in^2) resulted in a total contact pressure of 78.53 KPa (11.39 psi). With an empty tank the left tire produced an elliptical area of 507.1 cm^2 (78.6 in^2) resulted in a contact pressure of 85.08 KPa (12.34 psi). For a full tank the contact areas for the right and left tires were 1741 cm^2 (269.9 in^2) and 1671 cm^2 (259 in^2), respectively. The corresponding contact pressures were 123.42 KPa (17.90 psi) and 129.14 KPa (18.73 psi) for the right and left tires.

Plant Growth Stages

The same field was used for Experiments 2 and 3. Leaf counts and lengths were done at the same time. Results on Plant Growth Stage are the same as Experiment 2 results.

Slip Measurements

Slip measurement were done for all tank masses before each growth stage trial was completed. Using ASAE Standard S209.5 of the Agricultural Tractor Test Code, percentage slip was calculated. Slip measurements were completed at a speed of 8.1 km/h (5 mph) and a soil moisture content representative of the trial plots.

With 3637 L (800 gal) of water in the sprayer tank the average slip for the turf, lugged and tandem tires was 0.73%. Maximum slip of 1.29% was measured with the turf tire.

Soil Type

A Bouyoucos method soil particle analysis for the test plots included in Experiments 2 and 3 was completed. Refer to TABLE 8.

RESULTS

Crop yield results for the sprayer tire experiment varied from 5.4 to 16.8 kg (12.0 to 37.0 lb). The single turf tire yielded an overall average of 8.8 kg (19.5 lb). The tandem walking beam spray tires yielded an average of 10.5 kg (23.2 lb). Lugged tires yielded an overall average of 11.8 kg (26.1 lb). Average yields for the initial and final growth stages were 10.5 and 11.1 kg (23.2 and 24.5 lb), respectively. Results are located in TABLE 12 and FIGURE 3.

TABLE 12. Percentage of Control Yields for Trials

GROWTH STAGE (LEAVES)	TIRE TYPE	YIELD kg (lbs) BLOCK NUMBER 1	2	3
INITIAL (2 - 3)	TURF	05.4 (12.0)	05.9 (13.0)	12.7 (28.0)
	LUGGED	11.8 (26.0)	11.3 (25.0)	14.5 (32.0)
	TANDEM	06.4 (14.0)	10.4 (23.0)	12.7 (28.0)
	CONTROL	11.3 (25.0)	16.8 (37.0)	06.8 (15.0)
FINAL (Tillering)	TURF	06.4 (14.0)	10.4 (23.0)	12.2 (27.0)
	LUGGED	09.1 (20.0)	12.2 (27.0)	12.2 (27.0)
	TANDEM	08.2 (18.0)	12.7 (28.0)	12.7 (28.0)
	CONTROL	11.3 (25.0)	13.2 (29.0)	12.7 (28.0)

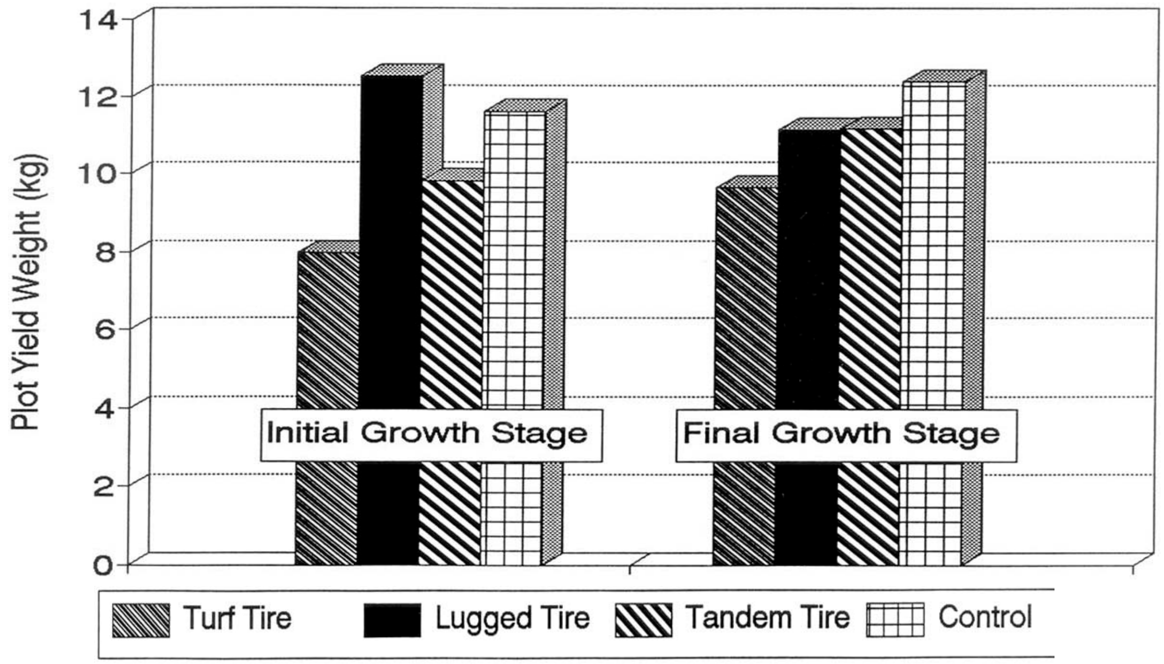

FIGURE 3. Turf/Lugged/Tandem Sprayer Results

Transport System Effects

Three different sprayer transport systems were used. No trends were apparent from the results. From the ANOVA analysis, the tire types did not provide significant differences in the crop yield.

Plant Growth Stage Effects

Two different plant growth stages were used for the test. The ANOVA results indicated no significant different at the 0.10 level. No trends were apparent.

RECOMMENDATIONS

Substantial testing is required to make general conclusions on crop reduction due to wheel traffic. Two factors affect crop yield reduction due to spraying operations; tearing of young plants by tire lugs, and the contact pressure being applied by the wheel to the plants and soil surface. Assuming tearing by lugs is minimal since no torque is applied to sprayer transport tires, contact pressure is the greatest concern. Concentration on compaction and considering the large number of variables which relate to soil compaction due to tire traffic, a method to eliminate as many variables as possible when studying soil compaction. Substituting a rigid wheel for rubber tires may be one method of eliminating the numerous variables involved in this research.

Dual tractor tires are sometimes used by farmers who believe that contact pressure is of greater affect on crop reduction than contact area. Research into tractor wheel slip and compaction relating to crop reduction is needed.

Yield results for Experiments 2 and 3 were done using a modified Case 960 combine. When differences of only 2 or 3 percent exist, sampling must be completed with a more reliable measuring devices or larger plot areas should be used. Plot size is also a concern which must be addressed. Making plots large enough to find differences in plots causes random errors due to different soil conditions, moisture and other field variations.

CONCLUSIONS

Based on the conditions of this test, the following conclusions could be drawn.

The later the spraying operation took place, the greater the amount of crop damage which occurred.

The mass of the tank when increased from 1818 to 3637 L (400 to 800 gal) did not significantly affect the reduction in yield due to wheel traffic. Mass on the tractor tires in Experiment 2 did not affect yield results.

Sprayer and tractor tires alone have smaller percentages of crop reduction than when sprayer tires are run in tractor tracks. However, if sprayer tires are not run in the tractor tracks, the overall percentage of crop reduction is greater than the reduction if the sprayer tires are run in the tractor tracks.

Single turf sprayer tires caused slightly less overall crop damage than the tandem walking beam assembly. However, the differences were not statistically significant.

No difference in yield was found when using single or dual tractor tires.

REFERENCES

Nebraska and OECD Tractor Test Nos. 1357, 1473. Tractor Testing Laboratory. Department of Agricultural Engineering, University of Nebraska, Lincoln, NE 68583-0832 USA.

ASAE Standard S209.5, Agricultural Tractor Code. ASAE Standards 1991, Standards, Engineering Practices and Data. 2950 Niles Road, St. Joseph, MI 49085-9659 USA.

ASAE Standard S313.2, Soil Cone Penetrometer. ASAE Standards 1991, Standards, Engineering Practices and Data. 2950 Niles Road, St. Joseph, MI 49085-9659 USA.