Application of Automatic Air Inflation Deflation Control System on a Manure Tanker to Prevent Excessive Soil Compaction

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Ahmad Mohsenimanesh

University of Ottawa

2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

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Application of Automatic Air Inflation Deflation Control System on a Manure Tanker to Prevent Excessive Soil Compaction

Mohsenimanesh, A., Laguë, C.

A. Mohsenimanesh, E.I.T., Ph.D., Research Associate[1]

C. Laguë, P.Eng., ing., FCAE, Ph.D., Dean[2] and Professor[1]

[1]Department of Mechanical Engineering

[2] Faculty of Engineering

University of Ottawa, Ottawa, ON, Canada, K1N 6N5

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Abstract. *An Automatic Air Inflation-Deflation (AAID) control unit was evaluated on a manure tanker to determine the best combinations of load and tire inflation pressure and to optimize the tire operational parameters for moderate and uniform distribution of the contact pressure. The tire footprint was characterized in terms of rut depth and width and soil physical properties (moisture content and cone index). Cone index was used as an indicator of increased soil strength caused by the weight of the manure tanker. Cone index values were significantly lower for the undisturbed soil compared to the soil that had been trafficked by tanker tires for all treatments. It was also observed that, as load was increased, rut width increased. This would be due to the bulging of the tire sidewall making contact with the soil, and therefore increase in the width of the soil-tire contact area. Conversely, when inflation pressure was increased, rut width decreased significantly with increased inflation pressure. Rut depth at the center and edge was affected by both inflation pressure and load. The degree of soil deformation was also investigated and the comparison results between the tire pressure of 300 and 100 kPa at a high load showed that the adjusted tire pressure using the AAID control unit could reduce the rut depth by 47 and 23% at the tire lug centerline and edge respectively.*

Keywords. *Soil Compaction Management, Automatic Air Inflation Deflation, Manure Tanker, Tire Footprint, Rut Depth, Rut Width, Cone Index.*

Introduction

Socio-economic considerations have progressively favored the use of larger, heavier and more productive machines and equipment to complete agricultural field operations (Gysi et al., 2001). The increased weight of agricultural machines, often coupled to the necessity of completing operations under unfavorable weather or soil conditions, increases the risks of traffic-induced soil compaction. Soil compaction is directly related to the increase in bulk density and, conversely, to a decrease in soil porosity, resulting from applied loads, vibration, or pressure. Controlled traffic systems can prevent such problems by restricting all machine traffic to permanent lanes (Laguë et al., 1997). Further benefits could accrue from reduced soil compaction where guidance technology in effect leads to controlled traffic farming systems (Luo et al., 2013). Reducing soil-tire contact pressure by using oversized tires or modifying running gear systems is another approach which has been studied for the particular case of liquid manure land application equipment (Bédard et al., 1997; Chi et al, 1993a and b). Relationships between dynamic load and inflation pressure on soil-tire contact pressure and rut size were also investigated and the results showed that increase in inflation pressure at constant dynamic load decreased rut width, total contact length, and total contact area of the tire (Mohsenimanesh and Ward, 2010, 2009 and 2007, Mohsenimanesh et al., 2009; Mohsenimanesh et al., 2008). Increases in load at constant inflation pressure increased rut width, rut cross-sectional area, and soil-tire interface pressures.

Knowledge of soil compaction and of the relationship between soil compaction and agricultural crop systems are important inputs for effective management of soil physical condition to improve crop production (Schafer et al., 1992). The desired degree of compaction depends on the intended purpose; for example, the requirements for traction and mobility are quite different from those for water infiltration and root propagation. To minimize compaction the load must be reduced along with tire inflation pressure. To maximize pull, the tire load must be increased which increases soil compaction. What most farmers settle for is a compromise that provides enough tire pressure and load to get their heavy field work done while using a tire size or sizes that operate at as low an inflation pressure as possible within the range of tire dimensional limitations (Ellis, 1977).

One technology that could potentially advance the use of intelligent transportation systems is the intelligent tire concept with sensors embedded in the tire (Taheri, 2011). Tire pressure monitoring systems use pressure sensing transmitters mounted inside each tire to constantly monitor air pressure and temperature as a warning system (Matsuzaki and Todoroki, 2008; Sankaranarayanan and Guvenc, 2007). The advanced method of tire pressure monitoring is the active tire pressure system that measures tire pressure of vehicles, transmits and receives the data using radio frequency (Lee et al, 2008). These authors found that the developed system had stable communication performance having over 80% in reception success ratio.

Agribrink Inc. is a Canadian company that manufactures and distributes an Automatic Air Inflation Deflation (AAID) control system. The AAID is a prototype technology that can adjust the tire pressure of field equipment while the equipment is in motion to prevent excessive soil compaction problems. This system can inflate or deflate vehicle tires to accommodate different rolling surface conditions. Reducing tire pressure when vehicles are operated on deformable surfaces, such as agricultural soils, allows the tire footprint to become wider and longer. This increases the contact surface area and thus reduces the soil-tire contact pressure, therefore reducing the risks of excessive traffic-induced soil compaction. Although, the AAID system had been commercialized by Agribrink Inc. for application on heavy agricultural equipment, its effectiveness had not yet been validated from an engineering perspective in order to confirm its benefits for field agricultural operations. In addition, the company had encountered some challenges in extending the application of their system to different types of agricultural equipment whose total mass continuously vary during field operation (e.g. wagons and carts collecting forage or grain from harvesting equipment on the go, large balers, manure and slurry land application equipment). The particular case of manure tanker needed to be investigated in that regard in light of the loading and contact pressure conditions that were specific to it. This allowed for the identification of the best combinations of load and inflation pressure operating conditions. Therefore, an experiment was developed with the following objectives:

1- To evaluate of the AAID control system on a commercial manure tanker;
2- To determine the effect of load and inflation pressure on cone index, rut depth, and tire footprint;
3- To recommend the best combination of load and tire inflation pressure for optimization of contact area for different vertical loads.

Material and Methods

The field experiment was conducted at the Moorefield Farm, Ontario. Tires used for the experiment were Michelin

850/50 R30.5 floatation tires. The experiment was designed with two levels of load (71.13 and 35.56 kN) corresponding to the full and the half load of the manure tanker respectively, and two levels of inflation pressure (50, 100 kPa) and conducted under constant travel speed. At high load, the levels of inflation pressure were extended to (200 and 300 kPa) to provide more information about the tire and its impact on soil (Table 1). Figure 1 shows the manure tanker and the AAID control system used for the experiment.

Table 1. Load and inflation pressure combination for the Michelin tire (850/50R30.5)

Treatment	Load (kN)	Inflation Pressure (kPa)
31.5-50	31.5	50
31.5-100		100
71-50	71	50
71-100		100
71-200		200
71-300		300

In addition, an Alliance 30.5LR32 flotation tire was used to determine the effects of inflation pressure and load on cone index, rut depth and width. The experiment was conducted under two levels of tire pressure (200 and 300 kPa) at the high load value of 56.93 kN. The load was measured statically by using a set of electronic weighing pads.

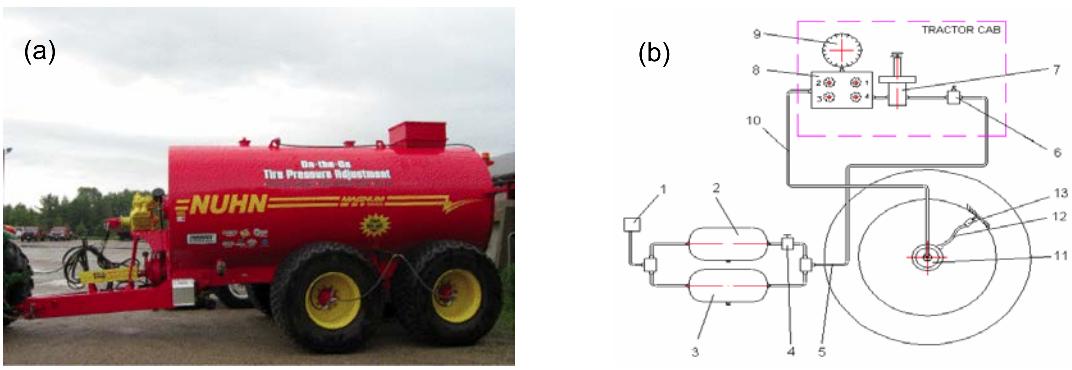

Fig 1. The manure tanker and the AAID control system (a) compressor and airlines connected to tires (b) Schematic of the AAID control system 1- tractor's compressor; 2- tractor's compressed air reservoir; 3- additional compressed air reservoir; 4-stop valve; 5- supplying pipe; 6- direction valve; 7-pressure regulator; 8- group of control valves; 9- pressure gauge; 10- connecting pipes with air distributor; 11- rotating air distributor; 12- connecting pipes with wheels shutter.; 13- wheel shutter (Adapted from Popescu et al, 2011).

The experimental design was a randomized complete block (RCB), and each trafficked lane was divided into four blocks. Each block in each treatment had a tire footprint, which was used to measure rut depth, rut width, and soil physical properties such as moisture content and cone index. Rut depth was measured in the center and the side of the track. The cone penetrometer measurements were taken in an undisturbed soil area, in the center, and at the edge of the tire in the lug print area. The plots used for each treatment were 5 m wide × 20 m long. Prior to the experiments, the field was moldboard plowed followed by one pass of a rotary tiller. The average values of moisture content at the soil surface were measured.

Results and discussion

Cone index was used as an indicator of increased soil strength caused by the tanker tires. Differences were easily seen between the undisturbed condition and that caused by the manure tanker tire down to the hardpan layer (Figure 2). A statistical comparison was made among the cone index values measured in the undisturbed soil, at the center of the track, and at edge of the track. A significant difference ($p < 0.01$) in cone index was found for all treatments. Cone index was less for undisturbed soil than for trafficked soil at the center and edge of the tire track for all treatments. This is in agreement with previous works that have showed an increase in soil cone index after traffic (Mohsenimanesh and Ward, 2007; McDonald et al., 1996).

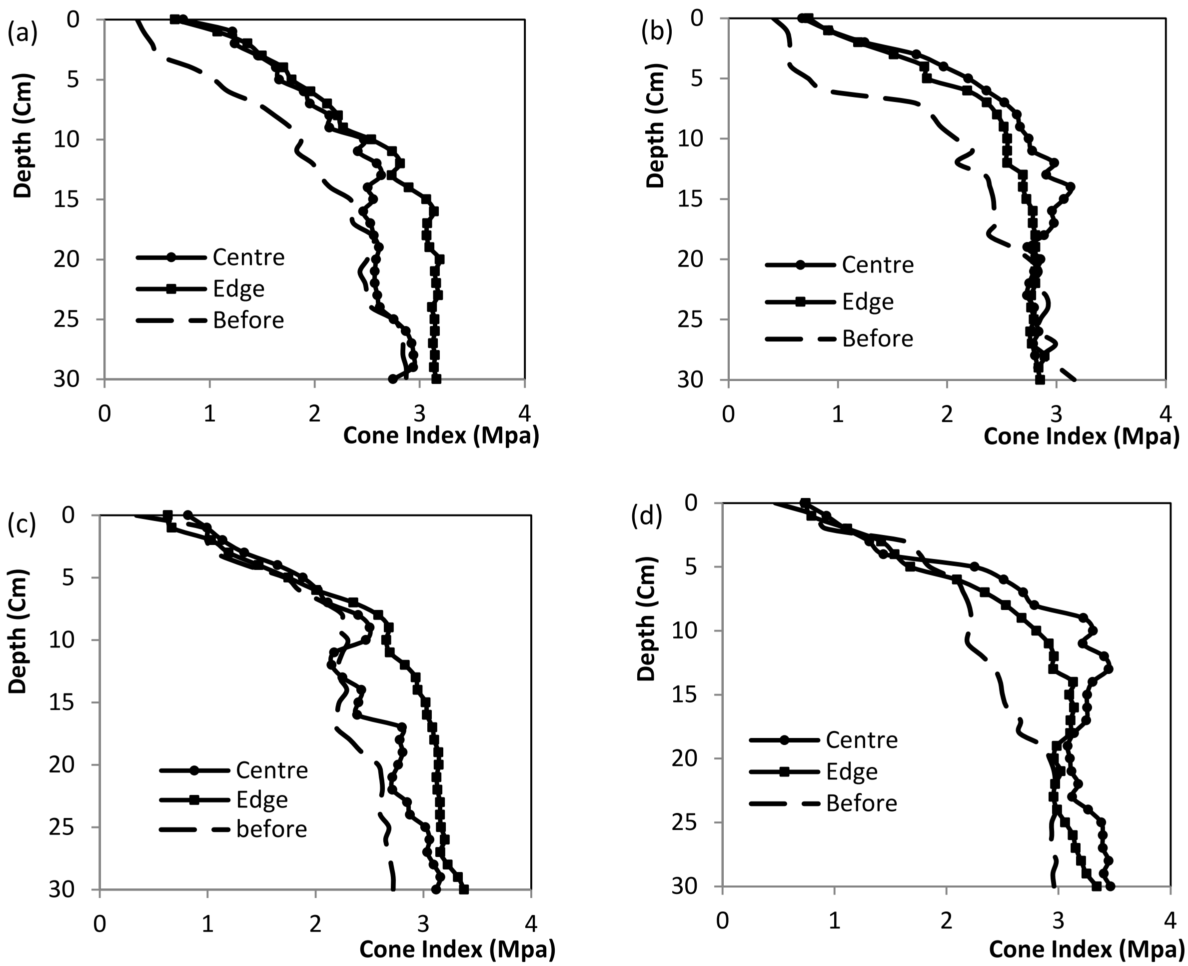

Figure 2. Cone index as measured in the track of a 850/50 R30.5 tire: (a) 35 kN load, tire inflation pressure of 50 kPa; (b) 35 kN load, tire inflation pressure of 100 kPa; (c) 70 kN load, tire inflation pressure of 50 kPa; and (d) 70 kN load, tire inflation pressure of 100 kPa.

An analysis of variance was used with load and inflation pressure as independent variables and the data averaged across the depth. Differences were also noted because of the load and inflation pressure effects. At the center of the tire track, only inflation pressure caused significant differences in cone index ($p < 0.0153$). Similar result was obtained when lower inflation pressures were used in soft clay soil (Mohsenimanesh and Ward, 2010 and 2007). Load appeared to have an effect at the center of the track, but there was no significant difference.

Comparison among treatments at the center of the tire track showed that the mean cone index increased significantly only in the 71-100 treatment, while there were no significant differences among treatments at the edge. However, the high load treatments had greater cone index in comparison with the low load treatments (Figure 3). At the edge of the track, inflation pressure and load appeared to have an effect, but there was no significant difference. However at the edge of the track, the high load and the high tire pressure treatments had greater and smaller cone index respectively in comparison with the low treatments.

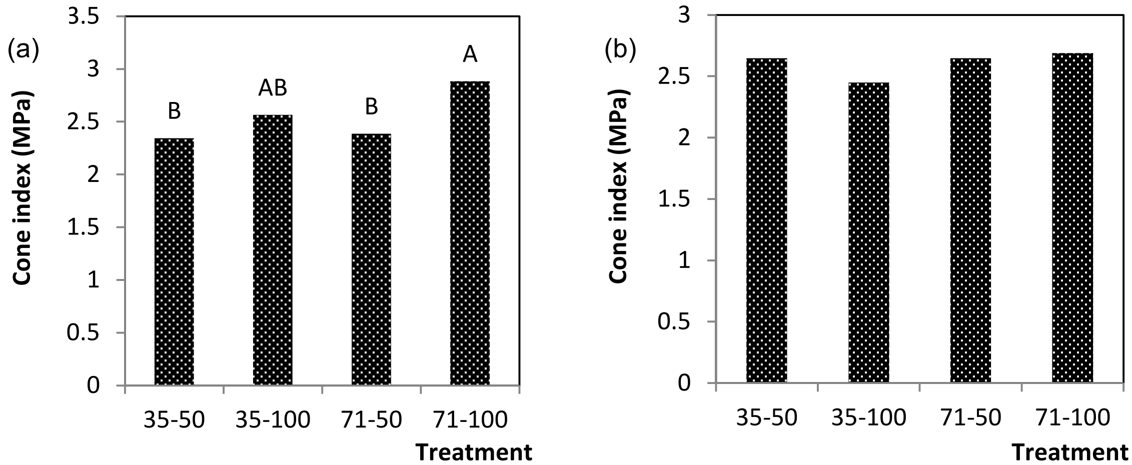

Figure 3. Interaction results for cone index (a) at the center and (b) at the edge of the tire track

Figure 4 shows the footprints for each of the inflation pressure and load combinations. The footprints for the 31-50 and 70-100 treatments, in which correct combinations of load and inflation pressure were used, are presented in figures 4A and 4D. The entire footprint was relatively constant along the contact patch at the center and edge on Figure 4A. The footprint for the 31-100, 71-200, and 71-300 treatments, which were the overinflated treatments, are presented in figure 4B, 4E, and 4F. As inflation pressure increased above that recommended by the tire industry, not only did the entire footprint become shorter, the contact length near the outer edge of the tire decreased. Such trends in footprint have been observed in studies on soil-tire interaction (Mohsenimanesh and Ward, 2007; Way et al, 2000; McDonald et al, 1996). The footprint for the 71-50 treatment, which was the underinflated treatment, is presented in figure 4C. As load increased above that recommended by the tire industry, the contact length near the outer edge of the tire and the entire footprint become longer. However, the tire footprint was relatively inconstant along the contact patch, especially at the tire center and middle (Figure 4c). Such trends in footprint have been observed in studies on soil-tire interaction (Mohsenimanesh and Ward, 2007; Way et al., 2000; McDonald et al., 1996).

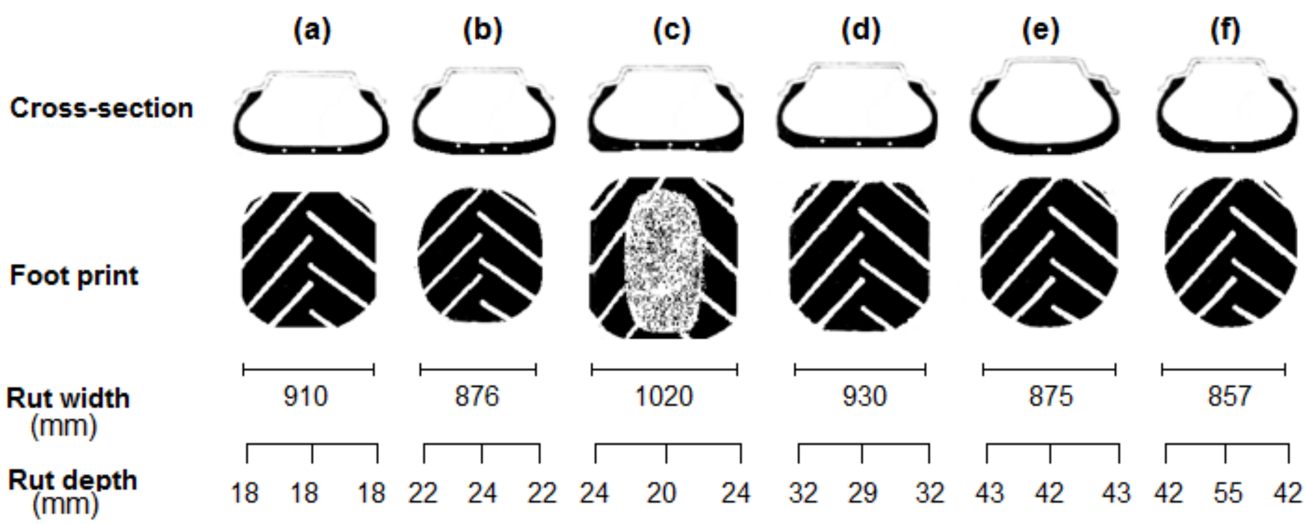

Figure 4. Mechanistic model of cross-section and footprint, rut width and depth of soil-tire interface for different loads and inflation pressures: (a) 31 load, tire inflation pressure of 50 kPa, (b) 31 load, tire inflation pressure of 100 kPa (c) 71 kN load, underinflated inflation pressure of 50 kPa; and (d) 71 kN load, correct inflation pressure of 100 kPa, (e) 71 kN load, overinflated pressure of 200 kPa; (f) 71 kN load, overinflated pressure of 300 kPa.

Rut depth was measured in the center and the side of the track and was used to investigate the effect of load and inflation pressure. Rut depth in the center was affected by inflation pressure ($p < 0.0001$). Rut depth at the edge was affected by load ($p < 0.0007$) (Figure 5). Increased tire pressure from 50 to 300 kPa increased rut depth at the tire center from 20 to 55 mm. Increased load from 31 to 71 kN increased rut depth at the tire edge from 21 mm to 27 mm. The comparison results between the tire pressure of 300 and 100 kPa at high load showed that the adjusted tire pressure using the AAID control unit could reduce the rut depth by 47 and 23% at the tire lug centerline and edge respectively.

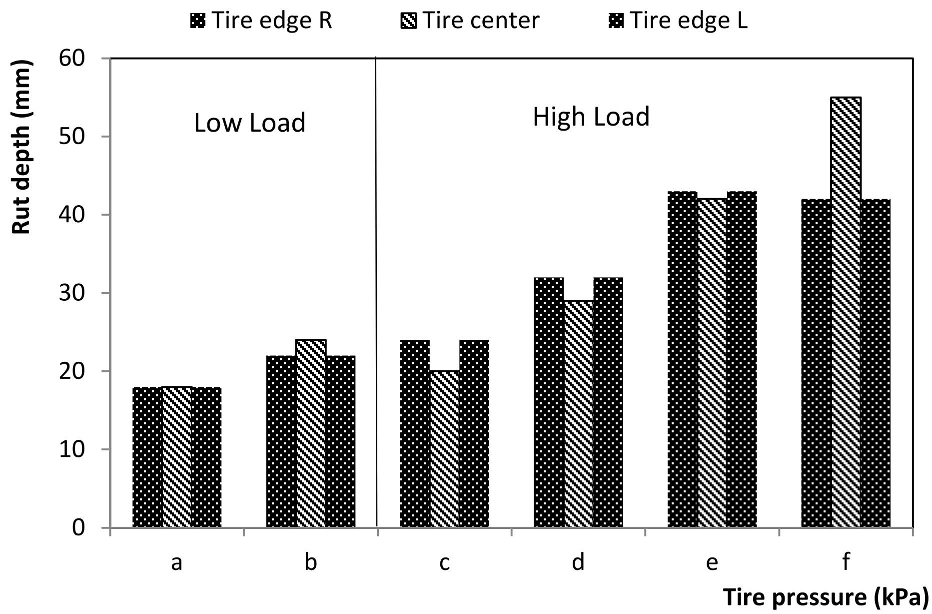

Figure 5. Rut depth of a 850/50 R30.5 tire for different loads and inflation pressures: a) 31 load, tire inflation pressure of 50 kPa, b) 31 load, tire inflation pressure of 100 kPa, c) 71 kN load, underinflated inflation pressure of 50 kPa; and d) 71 kN load, correct inflation pressure of 100 kPa, e) 71 kN load, overinflated pressure of 200 kPa; f) 71 kN load, overinflated pressure of 300 kPa.

As load was increased, rut width increased (Figure 6). Similar results were previously obtained when dynamic load increased across two kinds of soils (Norfolk sandy loam soil and Decatur clay loam soil) (Raper et al., 1995). This effect was probably due to the bulge in the tire sidewall penetrating farther into the soil and being measured as an increase in the width. As the inflation pressure increased, the tire became narrower with the side of the track so that rut width decreased.

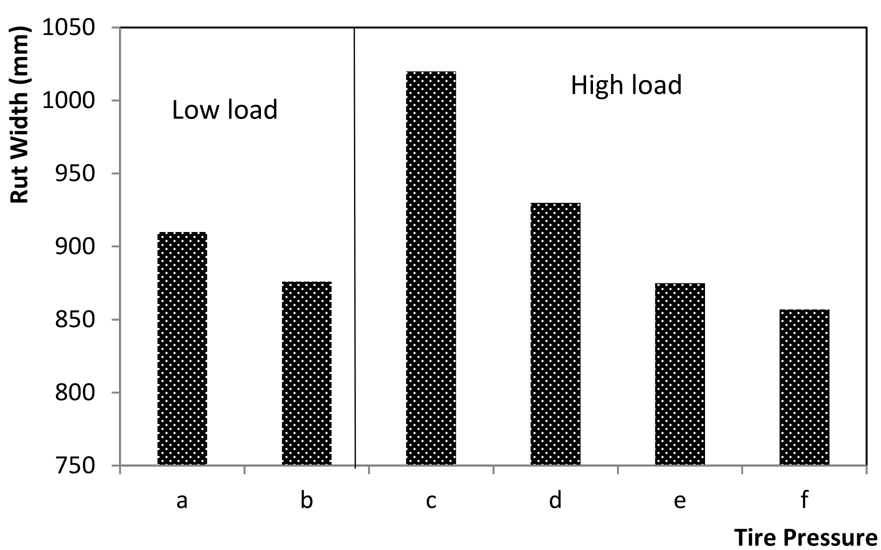

Figure 6. Rut width of a 850/50 R30.5 tire for different loads and inflation pressures: (a) 31 load, tire inflation pressure of 50 kPa, (b) 31 load, tire inflation pressure of 100 kPa (c) 71 kN load, underinflated inflation pressure of 50 kPa; and (d) 71 kN load, correct inflation pressure of 100 kPa, (e) 71 kN load, overinflated pressure of 200 kPa; (f) 71 kN load, overinflated pressure of 300 kPa.

Cone index was also investigated in the case of the Alliance 30.5LR32 flotation tire. Cone index was less for undisturbed soil than for trafficked soil at the center and edge of the tire track for both treatments. Increased tire pressure from 200 to 300 kPa and at 56.93 kN load increased soil strength at the tire lug centerline from top to subsoil (Figure 7).

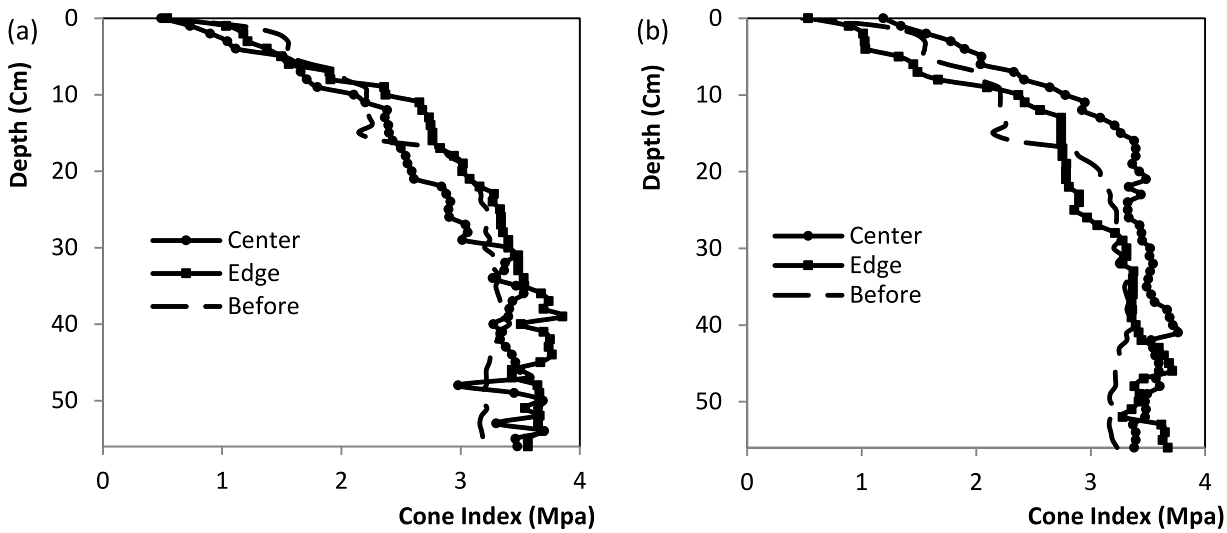

Figure 7. Cone index as measured in the track of a Alliance 30.5LR32 flotation tire: (a) 56.93 kN load, tire inflation pressure of 200 kPa; and (b) 56.93 kN load, tire inflation pressure of 300 kPa.

Rut depth and rut width were measured in the center and the side of the track for the Alliance 30.5LR32 flotation tire. Increased inflation pressure from 200 to 300 kPa at 56.93 kN load increased rut depth at tire centerline and decreased it at the tire edge (Figure 8a). As inflation pressure was increased, rut width decreased (Figure 8B). As the inflation pressure increased, the tire became narrower with less bulge near the side, and the tire penetrated farther into the soil at the center. This resulted in a cancellation of the effects of inflation pressure on the width of the rut (Figure 8b).

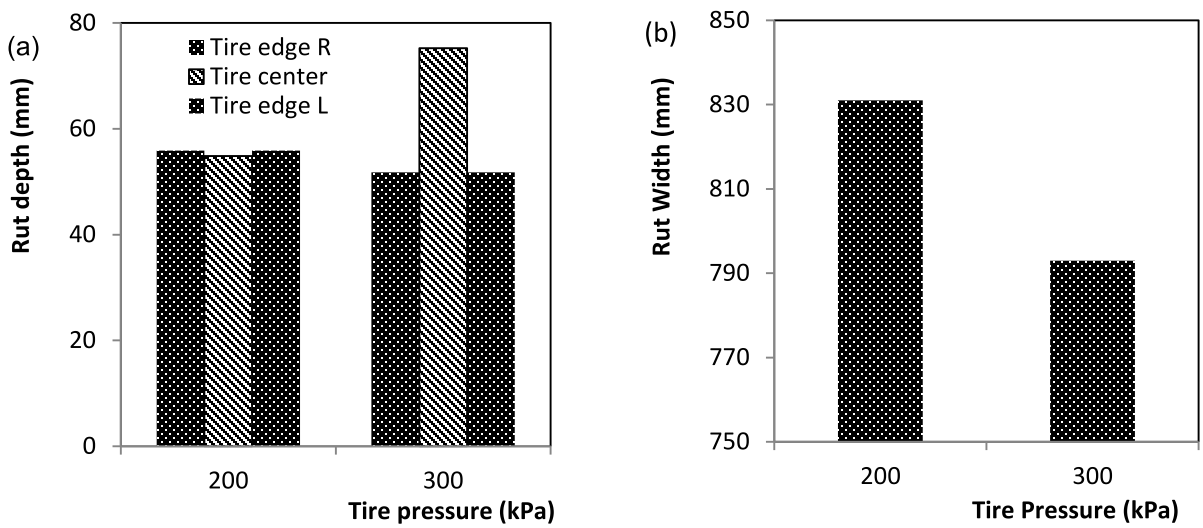

Figure 8. Rut depth and width under 56.93 kN load and tire pressures of 200 and 300 kPa.

Conclusion

1. The AAID technology used in this research is a prototype system, and it proved suitable for contributing to reduce excessive traffic-induced soil compaction.
2. Cone index, rut depth and footprint reflected the effect of tire inflation pressure more than load.
3. The adjusted tire pressure using the AAID control unit could reduce the rut depth by 47 and 23% at the tire lug centerline and edge respectively. These results could optimize the contact area by varying the payload weight.

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