Effects of Turfgrass, Cutting Height and Soil Conditions on Traction

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Abstract

Studies have been conducted to determine the effect of various turfgrass and soil conditions on the traction of athletic field surfaces. With the development of a new traction testing device (Pennfoot), it is desirable to re-examine the plant and soil characteristics affecting traction. The objectives of this study are to: 1) determine whether tall fescue verdure and cutting height affects translational traction over differing soil water contents; and 2) determine the effect of varying soil water content on the translational traction of four turfgrass species each maintained at three cutting heights. The presence or absence of verdure had little effect on traction of tall fescue (*Festuca arundinacea* Schreb.) turf. Lower cutting heights of tall fescue resulted in higher traction, presumably due to increased tiller density. As soil water content increased traction on tall fescue turf increased. Pennfoot detected traction differences due to species. Kentucky bluegrass (*Poa pratensis* L.) and tall fescue had higher peak traction measurements than perennial ryegrass (*Lolium perenne* L.) and chewing and red fescue (*Festuca rubra* L. ssp. commutata and *Festuca rubra* L. ssp. rubra). Traction measurements of tall fescue, perennial ryegrass, and red fescue were all negatively correlated with soil water content; however, Kentucky bluegrass traction measurements were not correlated with soil water content. Both turfgrass and soil characteristics impart an influence on traction; however, traction on natural turf is controlled by their combined effects. Ideally, traction results obtained with instrumentation will correlate to player's assessments of traction. Such comparisons need to be made in the future.

INTRODUCTION

An athletic field surface should provide a level of traction that benefits the player's actions without causing excessive stress to joints or ligaments. On natural turfgrass surfaces the soil and plant constituents, rainfall, and management practices such as mowing and irrigation affect traction (Canaway and Baker, 1993).

Researchers evaluating the effects of varying soil and turf conditions on traction have reported contradictory results. Gibbs et al. (1989), Winterbottom (1985), and Bell and Holmes (1988) found that traction was positively correlated with soil water content. In contrast, Baker (1991), Rogers et al. (1988) and McNitt et al. (1996) reported that traction negatively correlated with soil water content. Canaway (1983) found that annual bluegrass (*Poa annua* L.) and tall fescue had lower traction values compared to creeping red fescue, with Kentucky bluegrass and perennial ryegrass being intermediate and variable. Canaway (1975) and McNitt et al. (1997) reported that creeping red fescue provided lower traction values than perennial ryegrass and Kentucky bluegrass. McNitt et al. (1997) found that tall fescue frequently measured highest in traction compared to other species.

Athletes have expressed the opinion that traction is improved on turfgrass maintained at lower cutting heights. Rogers and Waddington (1989) found no difference in traction values among various cutting heights on tall fescue. The investigators found that by removing the verdure, traction values decreased. Richards and Baker (1992) reported that under extreme grass lengths traction decreased with increasing verdure of perennial ryegrass.

The varying and contradictory traction research results reported above may, in part, be due to the different environmental conditions of the studies and to the level of simulated traffic imposed on the plot areas. The varying results may also be due to the methods used to measure traction. Differences among methods include, measuring device surface that interacts with the turf, vertical force applied (loading weight), and horizontal force applied (rotational or linear).

In a review of the validity of methods used to evaluate the traction characteristics of a playing surface, Nigg (1990) suggested that tests provide relevant information only when appropriate shoe soles are used and when the actual vertical force (loading weight) applied is similar to that applied by athletes. Nigg (1990) concluded that using vertical forces lower than those created by an athlete may lead to erroneous conclusions. The method that can best simulate the interaction between an athlete's foot, the shoe, and the surface should provide the most meaningful measurement of traction.

We developed and tested an apparatus, termed Pennfoot (McNitt et al., 1996, 1997), that meets the footwear and loading weight requirements for valid traction evaluation set forth by Nigg (1990). Pennfoot is portable and can be used to measure traction in situ by either rotating the foot (rotational traction) or pulling it linearly (translational traction) across a turfgrass or other surface. With the development of Pennfoot, it is desirable to re-examine the turfgrass characteristics affecting traction.

The objectives of the this study are to: 1) determine whether tall fescue verdure and cutting height affects translational traction over differing soil water contents, and 2) determine the effect of varying soil water content on the translational traction of four turfgrass species each maintained at three cutting heights.

MATERIALS AND METHODS

Description and Operation of Pennfoot

Pennfoot consists of a frame, which supports a steel leg with a cast aluminum foot pinned on the lower end of the leg. We cast the simulated foot from a size 10 foot mold and the foot can be fitted with different athletic footwear. Two holes located on top of the foot are used for connection with the leg. The first hole located toward the toe allows to raise the heel off the ground and distribute the weight on the ball of the foot. All traction measurements in this study were performed with the forefoot in contact with the surface and the heel of the foot raised off the ground.

Pennfoot allows to measure rotational traction or translational traction. All measurements in the following experiments were made with Pennfoot configured to measure translational traction. The linear force is created by a single pulling piston that is connected to the heel of the foot. The pressure applied to the piston is created with a hand pump and monitored with a liquid-filled pressure gauge that is connected directly to the pump. The pressure readings are converted to Newtons (N) by multiplying the effective area of the pulling piston by the amount of pressure read from the gauge. We measure the distance traveled by the foot using a dial indicator. Traction is thus measured as the amount of horizontal force (N) required to maintain translational movement. In this study, the horizontal traction force was measured at seven increments of linear distance traveled (13, 19, 25, 32, 38, 44, 51 mm). For a thorough description of design rationale and construction details of Pennfoot see McNitt et al. (1997).

Experiment 1

In this experiment, our objective was to determine the effects of tall fescue verdure, cutting height, and soil water on traction. Traction was measured in June 1992 on plots located at the Landscape Management Research Center at the Pennsylvania State University. These plots were established with 'Kentucky 31' tall fescue in the fall of 1985. The soil was a Hagerstown silt loam (fine, mixed Mesic Typic Hapludalf) containing 8% sand, 66% silt, and 26% clay. The experimental design was a split block with three replications. Seven treatments were assigned to each block. Six of the treatments consisted of two plots of each of three cutting heights (23, 51, and 77 mm), which had been maintained since the plots were established. The verdure was removed on one of each of the three cutting height plots, in each block, by clipping the turfgrass plants to ground level just prior to traction measurements. This procedure resulted in three cutting height plots with verdure present and three cutting height plots with verdure removed. The seventh treatment was bare soil (also present since 1985) maintained with applications of glyphosate herbicide. Each plot was 0.9 m by 4.4 m. Blocks were randomly split by applying 50 mm of water over 40 min to one-half of each block. The water was applied by a rectangular arrangement of directional spray nozzles mounted on PVC pipe. We did not observe ponding at any time during the test.

Pennfoot was used to measure traction on the irrigated and non-irrigated plots approximately 20 h after irrigation was applied. We fitted the aluminum foot with a hightop molded football shoe (Nike, Inc., 150 Ocean Dr., Greenland, NH), which contained 18 triangular studs (12 mm long) around the perimeter of the sole and 35 smaller studs (9 mm long) in the center. Pennfoot was loaded with weights to give a total loading weight of 102.0 kg. All measurements were performed on dry turf: i.e., free of dew, precipitation, or irrigation water on the turf surface. For each combination of the seven treatments and irrigation treatment split, four traction measurements were made.

Experiment 2

In Experiment 2 we evaluated the effects of soil water content, species, and cutting height on traction. We measured traction in June 1992 on plots located at the Joseph Valentine Turfgrass Research Center at the Pennsylvania State University. Four grass species were established in August 1990. The species were 'Aspen' Kentucky bluegrass, Penn State 222 experimental perennial ryegrass, 'Pennlawn' creeping red fescue, and 'Arid' tall fescue. The soil was a Hagerstown silt loam. The experimental design was a split plot (cutting height), split block (irrigation) with three replications. We divided each species plot (5.49 m by 6.10 m) into three cutting height subplots (1.83 m by 6.10 m) for cutting heights of 38, 51, and 64 mm. Blocks were split by irrigation treatment with one half of each block receiving approximately 50 mm of irrigation water by the method described in Experiment 1. Traction measurements were made, using Pennfoot, approximately 20 min after irrigation ceased. During the 20 min period a sponge roller was pushed across the area several times to aid in drying of the leaf blades.

Pennfoot was fitted with a low-cut studded shoe that contained 12 cylindrical studs, each 12 mm long and 11 mm in diameter (Nike, Inc., Greenland, NH). The loading weight was 102 kg. For each combination of species by cutting height by soil water treatment, four traction measurements were made.

Turfgrass Stand Characteristics and Soil Properties

All subplots in Experiments 1 and 2 were characterized by extracting three 8100 mm^2 by approximately 51 mm deep plugs from each subplot. Plugs were trimmed to obtain a 2 cm soil depth. The procedure described by Lush and Franz (1991) was used to determine verdure dry weights and tiller densites. The below ground vegetation was determined by first washing the soil from the roots and then determining the percent organic matter by loss on ignition at 360^{o}C (ASTM F1647, 1998). We determined soil water content by extracting four 240 mm^2 by 15 mm deep plugs from each subplot at the time traction measurements were being made. These plugs were immediately weighed and then placed in an oven at 105^{o}C for 24 h and weighed again. Soil water content was determined on a dry weight basis (kg kg^{-1}).

Statistical Analysis

Mean values of the four subplot measurements were analyzed using the analysis of variance. The least significant difference (LSD) was calculated only when the F ratio was significant at the 0.05 level. Linear correlation values were determined between linear horizontal forces at 38 mm of linear distance traveled and turfgrass stand characteristics and soil water.

RESULTS AND DISCUSSION

Experiment 1

We found traction differences due to cutting height treatments from 19 mm to 51 mm of linear distance traveled (Fig. 1). As cutting height decreased, traction increased. On plots with the same cutting height, the removal of verdure did not affect traction. From 19 to 51 mm of linear distance traveled, the bare ground treatment had lower traction values than any of the treatments containing turfgrass.

The irrigation treatment yielded higher traction than the non-irrigated treatment only at 4.4 and 5.1 cm of linear distance traveled (Fig. 2). The irrigation treatment averaged 0.30 kg kg^{-1} gravimetric water content in the upper 15 mm of soil and the non-irrigated treatment averaged 0.20 kg kg^{-1}. Although not measured, stud penetration may have been deeper in the wetter soil and may have contributed to greater traction. There was no cutting height by soil water interaction.

Correlation coefficients between horizontal force at 38 mm of linear distance traveled and turf stand characteristics are shown in Table 1. The bare ground treatment was not included in this analysis. Tiller density consistently showed a positive correlation with horizontal force. As expected, tall fescue maintained at different cutting heights had different turfgrass stand characteristics. As cutting height increased, tiller density decreased and below ground vegetation increased. The negative correlation between horizontal force and below ground vegetation may not be a cause and effect relationship. Traction is probably more strongly influenced by tiller density than below ground vegetation. This is further illustrated when we consider the low traction measurements obtained from the bare ground treatments where no below ground vegetation was present.

Soil water content was positively correlated with horizontal force when data from both the irrigation and non-irrigation treatments were included in the analysis. Soil water content did not correlate with horizontal force when data from only the irrigation or non-irrigation treatment were included in the analysis.

Experiment 2

There were no interactions between species, cutting height, and irrigation treatments. Traction differences were detected among species at each increment of travel (Fig. 3). Kentucky bluegrass had higher traction than perennial ryegrass and red fescue at all increments of linear distance traveled. Tall fescue had higher traction than perennial ryegrass and red fescue from 38 to 51 mm of linear distance traveled.

Although tall fescue had horizontal force values similar to Kentucky bluegrass, horizontal forces for tall fescue were the most variable of the four species tested. Standard deviations were determined for each species from four horizontal force measurements taken on subplots maintained at a cutting height of 38 mm. The peak horizontal force values were used to calculate the standard deviation. Peak horizontal force values and standard deviations for each species are as follows: tall fescue 1467 N , 114; Kentucky bluegrass 1694, 35; perennial ryegrass 1414, 35; and red fescue 1414, 35.

Traction for species was measured over a range of soil water contents (0.18 to 0.34 kg kg^{-1}). Traction measurements differed due to irrigation treatments between Experiments 1 and 2. In Experiment 1, the average soil water content (0.30 kg kg^{-1}) of the irrigation treatment resulted in higher traction measurements than those in the non-irrigated treatment where the average soil water content was 0.20 kg kg^{-1}. In Experiment 2, traction measurements from the irrigation treatment were not significantly different from the non-irrigation treatment (average soil water contents were 0.34 and 0.18 kg kg^{-1}, respectively) (Fig. 5).

Although differences in traction due to irrigation treatments were not obtained in Experiment 2, force values in the non-irrigated treatment were consistently higher, by a range of 76 to 121 N, than force values in the non-irrigation treatment. Because of the experimental design, the significance of the irrigation treatments was tested using an error term with only two degrees of freedom. Although there was no treatment interaction between species and irrigation, the average force values obtained from Kentucky bluegrass did not decrease after irrigation as much as with other species. Species other than Kentucky bluegrass were negatively correlated with soil water content while Kentucky bluegrass did not correlate with soil water content (Table 2). It may be that the rhizomatous growth habit of Kentucky bluegrass enables it to provide higher traction under high soil water content where soil strength decreases, stud penetration increases, and the morphological characteristics of the grass become more important.

The effect of cutting height on traction in Experiment 2 was similar to the results found in Experiment 1. Force values for the 38 mm cutting height treatment were higher than those obtained from the 64 mm cutting height treatment (Fig. 5). Force values obtained from the 51 mm cutting height treatment were intermediate to the 38 and 64 mm cutting heights.

CONCLUSIONS

Under the conditions of these experiments, turfgrass maintained at lower cutting heights measured higher in translational traction. The increase in traction was not due to a reduction of verdure but possibly to a change in the morphology of the turfgrass plants (such as tiller density). It was concluded that reducing cutting height (verdure removal) would not increase translational traction until the morphology of the turfgrass changes in response to the new cutting height.

Significant traction differences were found among the turfgrass species tested. Traction for tall fescue and Kentucky bluegrass was greater than for perennial ryegrass and red fescue. Although the average traction measurements for tall fescue and Kentucky bluegrass were similar, tall fescue traction was more variable than Kentucky bluegrass. The variability in the tall fescue traction may be due to its bunch-type growth habit. Kentucky bluegrass may be preferred over tall fescue because it provides a more uniform playing surface with respect to traction. More research is needed to understand traction variability of turfgrass stands especially after a playing surface exhibits distinct wear patterns.

Kentucky bluegrass seemed to be less affected by changes in soil water content compared to the other species tested. This may be due to the rhizomatous growth habit of Kentucky bluegrass.

Much is known about the effect of various construction and maintenance practices on turfgrass stand characteristics. Very little information exists linking turfgrass characteristic to player performance. Ideally, results obtained with instrumentation will correlate to player's assessment of traction. Canaway et al. (1990) found some significant correlation between player's opinions and traction measurements. More comparisons of this type need to be made in the future. At present, it seems important to make traction measurements using methods that approximate the type of traction (linear or rotational), loading weight, and footwear that are similar to real conditions.

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Tables

Table 1. Correlation coefficients between linear force at 38 mm and turfgrass stand characteristics and soil water for plots in Experiment 1, excluding bare soil plots.

Linear force measured at 38 mm of travel	Soil water	Below ground vegetation	Verdure	Tiller density
Force (N) for non-irrigated treatments, (df=4)	0.75 ^{NS}	-0.74 ^{NS}	-0.40 ^{NS}	0.87 *
Force (N) for irrigated treatments, (df=4)	0.25 ^{NS}	-0.88 *	-0.17 ^{NS}	0.93 **
Force (N) across all irrigation treatments, (df=10)	0.71 **	-0.66 *	-0.23 ^{NS}	0.73 **

NS = not significant at 0.05 level
* = significant at 0.05 level
** = significant at 0.01 level

Table 2. Correlation coefficients (df = 4) for traction forces at 38 mm of linear travel between species and turfgrass stand characteristics and soil water content across all cutting heights and irrigation treatments for Experiment 2.

Species	Soil water	Below ground vegetation	Verdure	Tiller density
Red fescue	-0.96 **	-0.13 ^{NS}	-0.13 ^{NS}	0.04 ^{NS}
Ky. bluegrass	-0.76 ^{NS}	0.34 ^{NS}	-0.44 ^{NS}	0.42 ^{NS}
Pr. ryegrass	-0.91 *	-0.16 ^{NS}	-0.21 ^{NS}	0.21 ^{NS}
Tall fescue	-0.93 **	-0.27 ^{NS}	-0.26 ^{NS}	0.24 ^{NS}

NS = not significant at 0.05 level
* = significant at 0.05 level
** = significant at 0.01 level

Figures

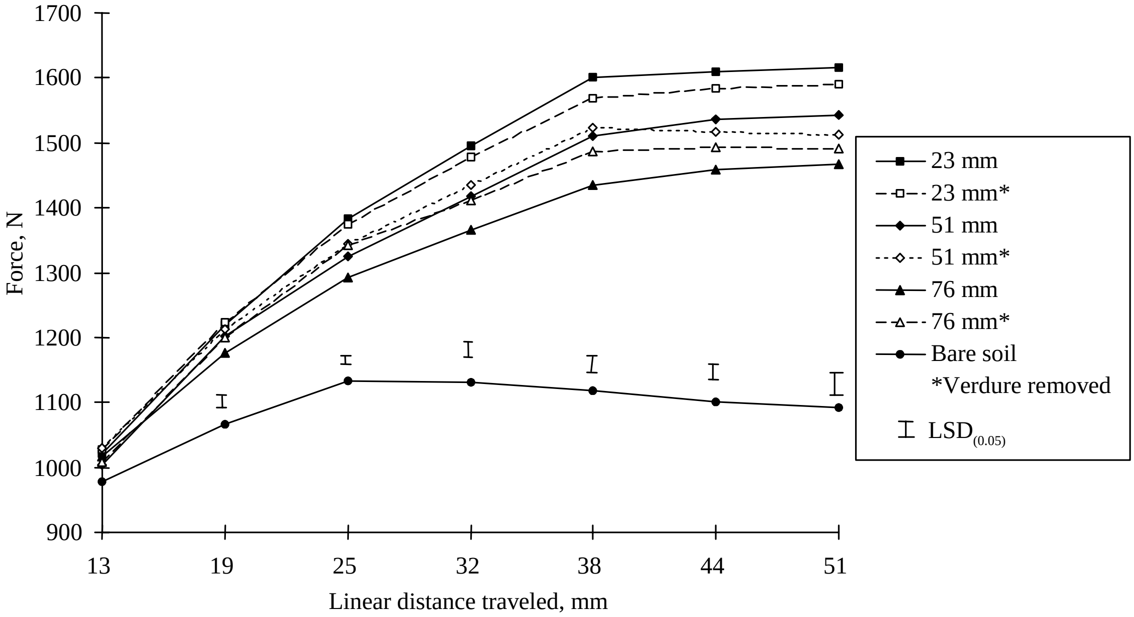

Fig. 1. Mean linear forces for cutting height treatments across water contents for Experiment 1.

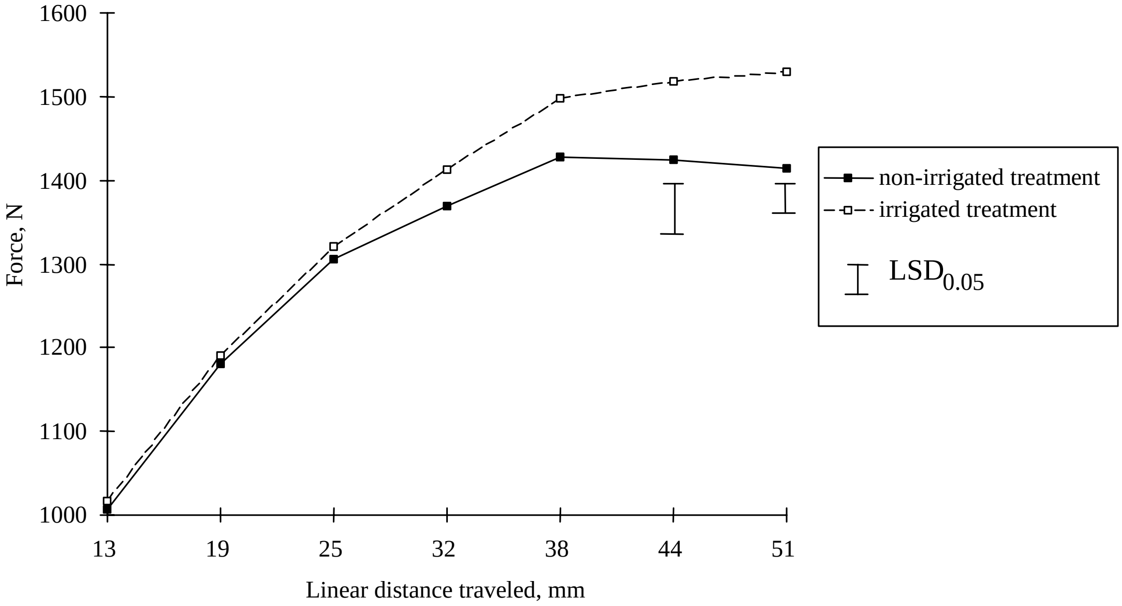

Fig. 2. Mean linear forces for irrigation treatments across all treatments for Experiment 1.

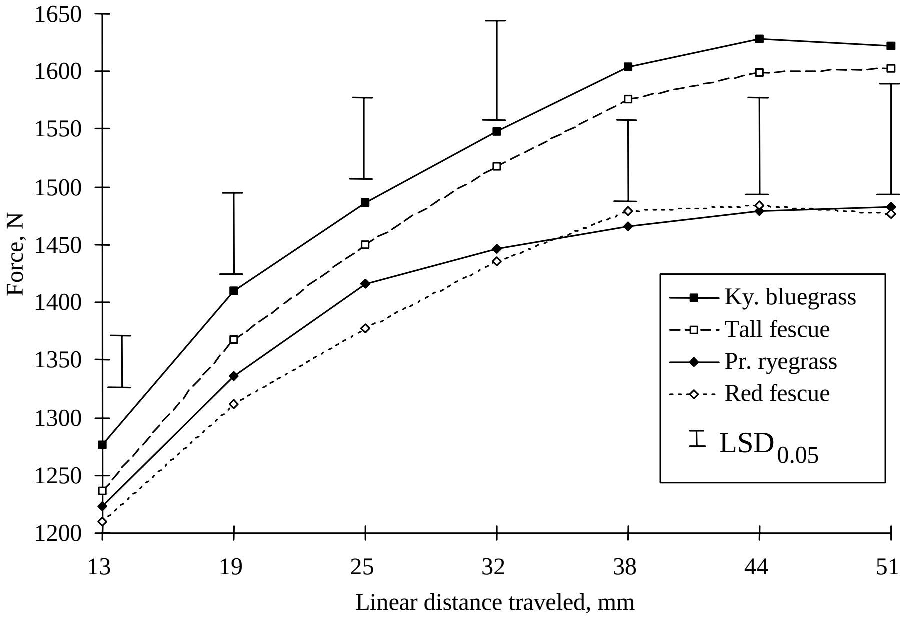

Fig. 3. Mean linear forces for grass species across cutting heights and irrigation treatments for Experiment 2.

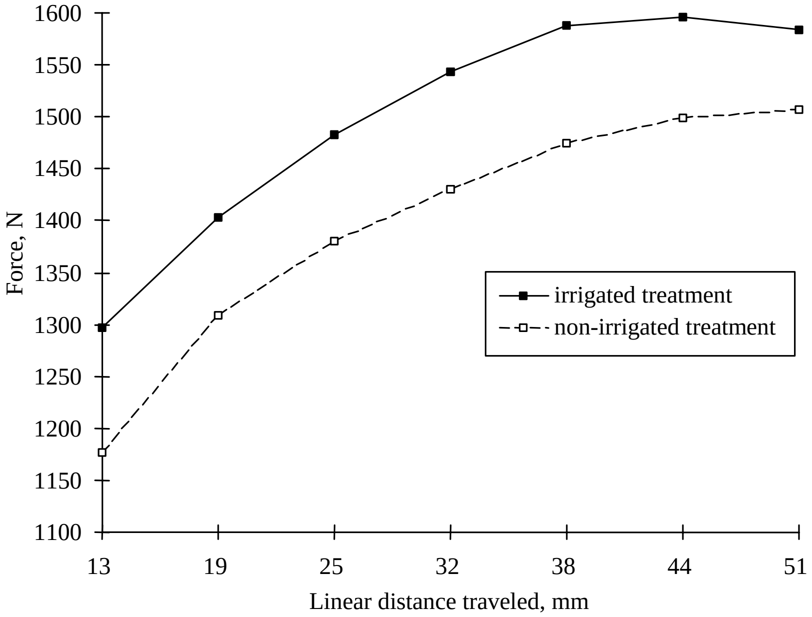

Fig. 4. Mean linear forces for irrigation treatments across grass species and cutting heights for measurements taken in Experiment 2. (Differences not significant at the 0.05 level).

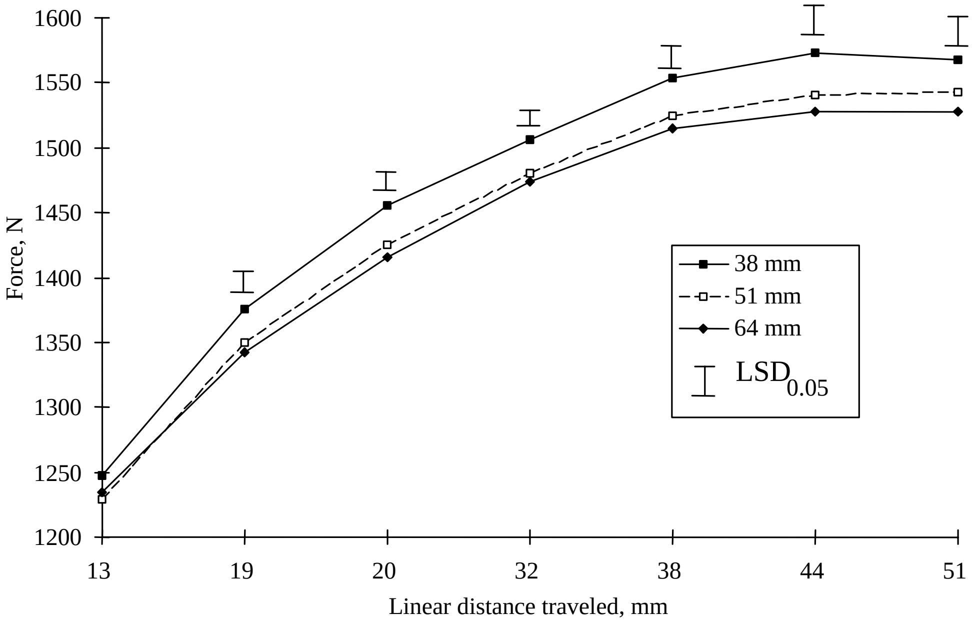

Fig. 5. Mean linear forces for cutting heights across grass species and irrigation treatments for Experiment 2.