length. Each day, a biomass weight was recorded until a constant biomass was realised using a sensitive digital electronic scale. The readings were averaged and recorded. This form of destructive sampling was done for 6 weeks in order to determine root biomass increment. Root biomass was significant across all treatments when $p< 0.05$, this is possibly because under irrigated conditions, maize roots do not grow deeper as water, phosphorous and other mineral elements are readily available within the proximity of roots. This corroborates with the findings by Mooney et al., (2012) who postulated that shallow roots are effective in scavenging for nutrients. Time and resources spent by roots in growing deeper is compensated through root hair development which together with other root sets like prop roots, brace roots and adventitious roots increasing root density. Increase in root density results in root biomass due to increased water and nutrient uptake (Robbins and Dinney, 2015). Liming increases soil pH promoting nutrient availability through enhanced root growth as well as microbial activity such as those of the abuscular vesicular micorrhizae fungi which improve root density and nutrient absorption. These findings also concur with the Garcia et al, (2015) studies. Treatments 3 and 4 revealed higher standard deviations which assumed an asymptotic pattern and increased variability or spreadness of data set/observations.

Lateral roots positively contribute to total underground (root) and aboveground biomass (Garcia et al., 2015). Root biomass recorded a significant difference in weight increment on a weekly basis for the six week evaluation period in all treated plots compared to the untreated plots .This was attributed to increase in root length, root density and root diameter. Roots naturally grow downwards due to the gravitropic environmental stimulus but this is exacerbated by the influence of specialised cells called statocytes as a result of sedimentation of intracellular statoliths (Galland et al, 2010). Geotropism/gravitropism is a vector since it possesses both magnitude and direction. Using the control treatment 1 with L0N0, any deviation from the mean of the control indicates the effects of liming due to root geotropic response. In all lime treatments, maize plants increased in root length, root biomass and divergence angle exponentially for the six week evaluation period. With no lime application, root biomass was insignificant and when lime and nitrogen were increased, results revealed a significant increase in root biomass. There was an insignificant increase when both nitrogen and lime rates reached point of inflexion. Considering the mean of all lime and nitrogen rates, optimum root biomass was recorded at nitrogen rates and lime rates $3t/ha^{-1}$L and

$0.2t/ha^{-1}N$. Beyond that, the results obeyed the law of diminishing yield increments as postulated by Bohm and Kirkham (1999) and Liebig and Mitscherlich, (1885).

Since root hairs increase root surface area for optimum water and mineral absorption, this manifestation depicts no surprise that it accounts for > 50% of root biomass. A combination of both long roots and dense adventitious/basal roots resulted in a 300% biomass in a study conducted using Field/Common beans (Phaselous vulgaris L.) (Monteros et al., 2015). This was attributed to optimum phosphorous acquisition since phosphorous improves root development. Young plants absorb phosphorous better and in maize this is optimum during the first 3 weeks after emergence.

Phosphorous availability in soils is low as it is most available at pH ~6.5, occurrence of phosphate rock is sketchy in Zimbabwe, combines with insoluble compounds in the soil in addition to its low diffusion rate of 0.015 – 1mm/hr (2cm day^{-1}) (Brady and Weil, 2008). This could have accounted for the low < root biomass in unlimed treatments in the study.

Results of the analysis of variance using the F-test also depict a significant interaction among the three factors namely Lime, Nitrogen and irrigation conditions when type 111 sum of squares has been factored in. This satisfies that the treatments to which belowground maize organs were exposed to vary significantly with seasons with an increase with successive seasons of lime applications. In both season 1 (2018/2019 and season 2 2019/2020) , Treatment L1N2 ($1.5t/ha^{-1}L$ and $0.2t/ha^{-1}N$)had the most significant effect on root biomass implying that a moderate lime application and optimal nitrogen rate are effective in promoting root biomass.

4.1 Root diameter

L1N1 has a significant effect to root diameter in both season 1 and 2. This is a confirmation of the results displayed in figure 4. However, in season 1 all treatment in the combinations were insignificant in influencing root diameter hence it is apparent from the results of this study that lime and nitrogen combinations have no significant effect in promoting root diameter .

Results of the analysis of variance using the F-test also reflect an insignificant interaction among the three factors namely lime, nitrogen and irrigation conditions when type 111 sum of squares was administered. This shows that the below ground maize parts, in particular root diameter, did not vary with seasons. In both season 1 (2018/2019 and season 2 2019/2020), only one Treatment L2N1out of the 8 treatment combinations had a significant lime – nitrogen interaction in influencing root diameter. This therefore, implies such treatment combinations have no significant positive effect in maize but could be more applicable in root crops like carrots, beetroot, parsnip and radish where root diameter matters most since the root structure is the edible part of economic importance.

As confirmed by post hoc Levene's Test of Equality of Error Variances and the Huynh-Feldt Tests inter alia, only the control L0N0, and L0N1as well as L2N1 had significant effects in influencing root diameter.

3.5 Root morphology/sets- prop/brace roots, crown roots and cluster or adventitious roots

Root angle and root morphology were examined from the 9 treatments over a period of six weeks. Root angle or divergence from the node was measured using a protractor, 45^o set square and 90^o set square. The development of the lateral roots signify the general root system architecture since the cumulative root density determine total root biomass (Robbins and Dinney, 2015). From the sampled plants, the minimum angle was $\geq$ 180^o. Root divergence angle increased with time for the period of evaluation. The Multiple Limitation Hypothesis (MLH) postulates that availability of one resource mineral element promotes the utilisation of other mineral elements. Availability of Ca, Mg, C supplied through $CaMg(CO_3)_2$/dolomitic lime as well as nitrogen used a treatment variable could have promoted the availability of other mineral elements. Liming increases the pH of the soil, providing a conducive environment for nutrient acquisition and plant organ development.

Studies using soy bean and wheat concluded that plants with more lateral roots are better adapted to phosphorus limited soils due to over expression of the β-expression gene which enhances RSA and phosphorous use efficiency due to increased lateral roots (Hufnagel et al., 2014). There was a correlation between root depth, root density and drying down rate or senescence and kernel yield.

5.0 CONCLUSIONS

Undesirable soil pH for plant growth and poor nutrient management affect crop productivity. The problem of soil acidity has affected agricultural productivity globally. Lime-nutrient interaction needs further research to determine specific lime and nutrient requirements. Different soils require lime and nutrient application rates. Sandy-textured soils are prone to nutrient loss through leaching particularly of mobile nutrients. Plant roots vary greatly in terms of depth, morphology, development and their chemotropic, geotropic and hydrotropic responses.

Maize plant roots are sensitive to soil pH thus impacting on above plant biomass. The availability of one plant nutrient in the soil continuum affects utilisation of other nutrients. Root architecture can be manipulated through agronomic and mineral nutrient practices. The elasticity of maize plant roots can best be understood under different stress field conditions. Root density and depth delays the drying down rate (DDR) or senescence of maize thus increasing their 1000 seed weight.

Whilst lodging in maize can be partly genetic, climatic, it can also be a function of root system architecture influenced by both soil fertility management. Maize develop different types of roots such as prop/brace roots, crown roots and cluster or adventitious roots as a result of chemotropic and hydrotropic root response. Shallow roots are less beneficial in withstanding water-stress conditions and overall nutrient uptake but are efficient in foraging and utilisation of immobile elements like phosphorous.

Both coefficient of variations (C.Vs) for Root Length and Root Biomass were $\leq$ 15% thus revealing the suitability of the experimental design, sample size and sampling technique. Higher standard deviations (SD) such as those recorded in treatments 3 ad 4 for root biomass reveal kurtosis which is critical for comparison with other treatments. The coefficient of variations (C.Vs) of field crops like maize or corn should not exceed 15% as was the case in this study.

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