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## Forage legumes exhibit a differential potential to compete against maize and weeds and to restore soil fertility in a maize-forage legume intercrop

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### ABSTRACT

Integrating forage legumes with maize has the potential to restore soil fertility and increase grain yield among smallholder farming systems. A study was conducted over two cropping seasons to determine the effect of intercropping maize with forage legumes on soil fertility restoration, weed biomass and maize yield. Treatments involved: four cropping systems (sole maize, maize-velvet bean, maize-silverleaf, maize-cowpeas) and four fertiliser regimes (no fertiliser, 150 kg ha<sup>-1</sup> of compound D fertiliser (7% N: 14% P<sub>2</sub>O<sub>5</sub>: 7% K<sub>2</sub>O) + 150 kg ha<sup>-1</sup> ammonium nitrate (34.5% N), 100 kg ha<sup>-1</sup> single super phosphate (SSP, 17.5% P<sub>2</sub>O<sub>5</sub>) and 200 kg ha<sup>-1</sup> SSP). Maize-velvet bean intercropping reduced weed biomass by 80% relative to sole maize and maize-silverleaf intercropping. Maize-cowpea and maize-velvet bean intercropping reduced maize grain yield by 25.9% and 64.7%, respectively, compared to sole maize and maize-silverleaf intercropping. In 2017/2018, maize-silverleaf intercropping increased resin-extractable P<sub>2</sub>O<sub>5</sub> by 60.1% compared to other cropping systems while the three fertiliser treatments increased the levels of this nutrient by 41.9–100%. The results of this study show that intercropping maize with silverleaf has the potential to restore soil fertility and control weeds, without reducing maize grain yield.

### ARTICLE HISTORY

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### KEYWORDS



Intercropping; legume biomasses; maize grain yield; soil fertility restoration; weed biomass

## Introduction

Maize (*Zea mays* L.) is the most important cereal grown in Zimbabwe, serving as a staple food crop for 99% of the population (Mashingaidze 2004). Approximately 70% of arable land on which maize is produced by smallholder (SH) farmers in the country is characterized by Fersiallitic sandy soils (Nyamapfene 1991). These soils are of low inherent fertility, with moderate phosphate sorption capacity, and high susceptibility to leaching and degradation (Nyamapfene 1991). The soils, like in most sub-Saharan Africa (SSA), are low in pH, buffering capacity, and organic matter content and have severe macro- and micro-nutrient deficiencies (Soropa et al. 2018). They also exhibit a general lack of response to mineral fertiliser addition (Nezomba et al. 2015) and have poor physical and structural protection of organic matter from degradation (Chivenge et al. 2007). Furthermore, these soils tend to be productive only during the initial years of cultivation but rapidly lose their fertility with time as the organic matter accumulated from natural vegetation is quickly mineralized (Six et al. 2002). Strategies such as cattle manure and inorganic fertilisers application, conservation farming,

micro-dosing and liming have been used to boost mineral nutrient reserves and soil organic matter in SSA soils (Munera-Echeverri et al. 2020). Rusere et al. (2019) suggested that minimising losses from the pedosphere or soil solum, creating a positive soil C budget, while enhancing biodiversity and strengthening water and elemental cycling are good strategies in restoring soil fertility.

However, the effectiveness of the above strategies depends on the availability of soil amendments such as lime, inorganic fertiliser and organic resources to farmers. Smallholder farmers in Zimbabwe, like most farmers in SSA, often have limited access to inorganic and organic fertilisers and apply suboptimal amounts that are not able to replenish mineral nutrients depleted through crop uptake, runoff and leaching (Kurwakumire et al. 2014). These soils, therefore, easily become degraded as a result of extractive and low external input soil management practices that are prevalent in the SH farming sector in SSA (Nezomba et al. 2015). The rapid degradation and decline in soil fertility have partly contributed to lower maize grain yields of between 0.4 and 0.9 t ha<sup>-1</sup> that is obtained by SH

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farmers compared to 6–12 t ha<sup>-1</sup> achieved by large scale commercial farmers who have greater access to fertiliser inputs (Gunjal et al. 2010).

Apart from degraded soils, inadequate and untimely weed control is also a major constraint for improved crop productivity, profitability and sustainability in the SH farming sector (Bastiaans et al. 2008). Weeds exacerbate the poor yields obtained from degraded soils by worsening mineral nutrient deficiencies when they remove scarce mineral nutrients that should accrue to crops, from the soil (Su et al. 2018). Numerous studies have shown that weeds are more adapted to compete for consumable resources against crops by pre-emptively extracting mineral nutrients and water before crops, and therefore potentially exacerbating mineral nutrient deficiencies for crops in soils of low fertility (Bastiaans et al. 2008). Weeds have a distinctive ability to grow vigorously and capture growth resources more efficiently than crops and, in some cases, inflict allelopathic effects on crops through their depressive root exudates (Dekker 2009).

The adoption of improved and sustainable farming technologies such as the use of integrated soil fertility management practices which encompass intercropping of cereals with legumes may be effective interventions for increasing maize grain yield in smallholder cropping systems (Sanginga and Woomer 2009; Matusso et al. 2014). These technologies have the potential to restore and maintain soil fertility through their ability to biologically fix atmospheric nitrogen, while simultaneously suppressing pests, diseases and weeds (Giller 2001; Sanginga and Woomer 2009). Intercropping maize with pasture legumes increases total plant density and hastens canopy closure by the component crops. Since the critical period for weed control coincides with the duration of the period from maize crop emergence to its full canopy cover, maize–legume intercropping has the potential to reduce the critical period for weed control and therefore the number of times the crop needs to be weeded to avert yield loss (Fan et al. 2012). Studies by Khan et al. (2002) showed that some forage legumes such as silverleaf (*Desmodium uncinatum* L.) have the potential to reduce the infestation of maize by parasitic witchweeds such as *Striga hermonthica* and *Striga asiatica*.

Cereal-legume intercropping systems have proved to be more effective in improving grain yield when they are accompanied by the application of phosphate fertilisers (Wang et al. 2017). There is also evidence that maize uptake of P increases when it is intercropped with Faba bean (Li et al. 2007). Li et al. (2007) also found that the application of P fertilisers in a maize-Faba bean intercrop increases agricultural productivity. Nezomba et al. (2015) reported that, coupled with P

fertilisation, herbaceous legume species provided the greatest potential to reverse soil degradation and increase crop productivity in SH farming systems.

Maize-legume intercrops by most SH farmers in SSA commonly include edible legumes such as common bean (*Phaseolus vulgaris* L.) and cowpea (*Vigna unguiculata* L.) (Matusso et al. 2014) to ensure household food and nutrition security. There is little documented research on the potential use of forage legumes for soil fertility restoration and weed suppression in maize-based cropping systems in SH farming systems. In this study, it was hypothesized that the use of forage legumes as live mulches coupled with the application of inorganic fertilisers in maize cropping systems has the potential to increase maize grain yield, replenish depleted soil mineral nutrients and reduce weed infestation. The objective of the study was to assess the potential of different maize-forage legume intercrops and fertiliser application regimes to suppress weeds, increase maize yield and restore the fertility of a degraded Chromic Luvisol.

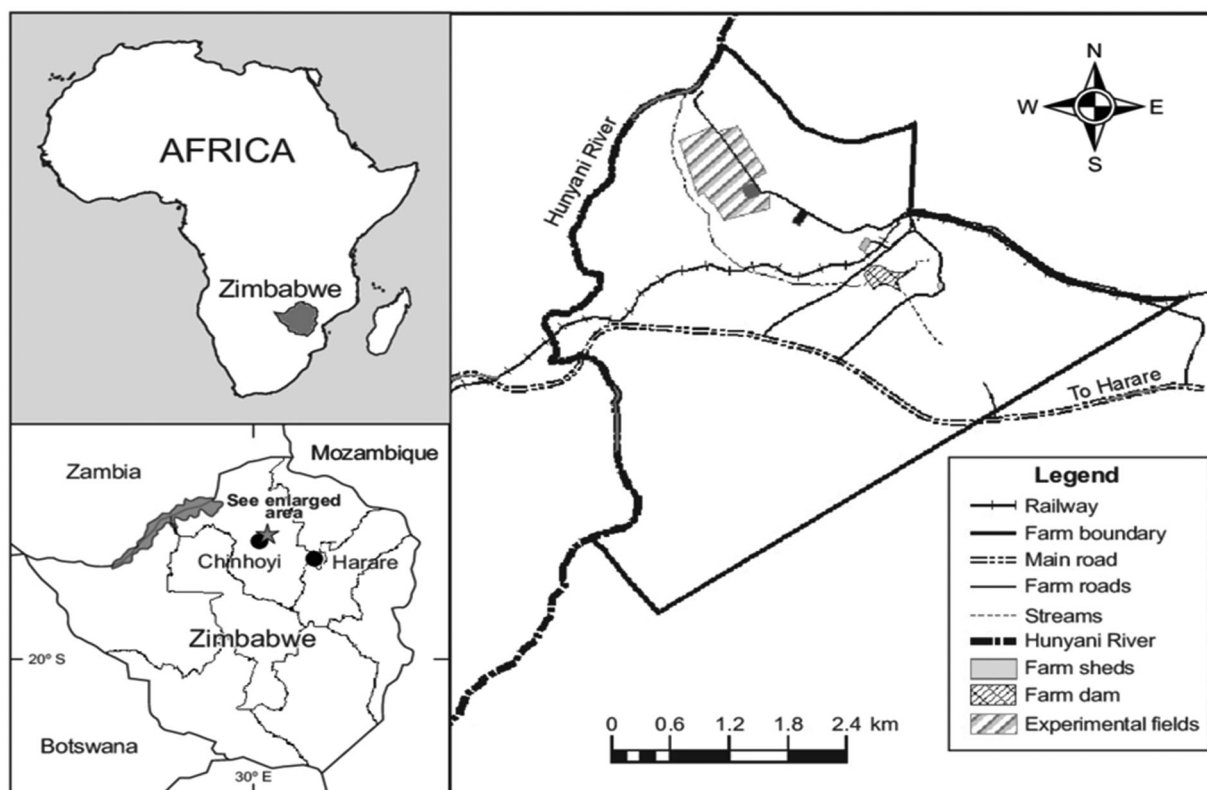
## Materials and methods

### Study site description

The experiment was conducted on two different fields during the 2016/2017 and 2017/2018 cropping seasons at the Chinhoyi University of Technology Hunyani farm (17°21'0.00"S, 30°14'0.00"E and an elevation of 1158 m above sea level) in Chinhoyi, Zimbabwe, under rainfed conditions (Figure 1). This site experiences wet and warm summer and dry and cold winters, receiving an approximate rainfall of 800–1000 mm per annum, with annual maximum and minimum temperatures of 29.9°C and 18.9°C, respectively (Bere et al. 2014). Total rainfall recorded for Hunyani farm in Chinhoyi was 890 and 600 mm in the 2016/2017 and 2017/2018 cropping season, respectively (Figure 2). The soils in the area are generally red Chromic Luvisols (FAO-UNESCO classification system) with high silt and fine sand content and an argillic sub-surface horizon making it prone to surface capping (Nyamapfene 1991; Kodzwa et al. 2020). Initial characterisation of soils at the specific site for this present study revealed that they had medium-grained sand clay loam mainly lacking in nutrients, namely N, P and exchangeable bases (Table 5).

### Experimental design and layout for 2016/2017 and 2017/2018 cropping seasons

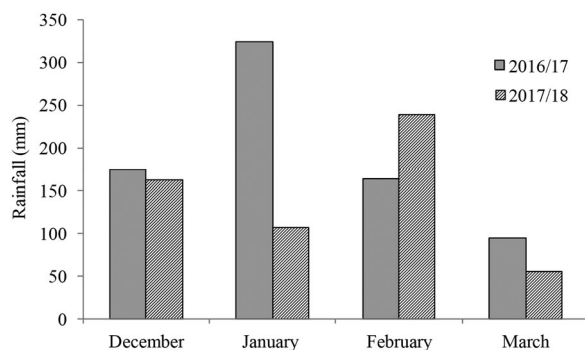
The treatments were laid out as a 4 × 4 factorial experiment in a randomized complete block design. Factor 1



**Figure 1.** Map of Africa showing the study area in Zimbabwe (Chinhoyi University of Technology Hunyani Farm). Source Mashavakure et al. (2019).

comprised four cropping system treatments: sole maize, maize-velvet bean (*Mucuna pruriens* L.) intercrop, maize-silverleaf (*Desmodium uncinatum* L.) intercrop and maize-cowpea (*Vigna unguiculata* L.) intercrop. These four cropping systems were combined with four fertiliser regimes (none,  $150 \text{ kg ha}^{-1}$  of compound D fertiliser (7% N, 14%  $\text{P}_2\text{O}_5$ , 7%  $\text{K}_2\text{O}$ , 8% S) +  $150 \text{ kg ha}^{-1}$  ammonium nitrate (AN, 34.5% N),  $100 \text{ kg ha}^{-1}$  single super phosphate (SSP, 19.5%  $\text{P}_2\text{O}_5$ , 18%  $\text{Ca}^{++}$ , 12.5% S) and  $200 \text{ kg ha}^{-1}$  SSP) (Table 1). There were, therefore, 16 treatments, each replicated four times. Experimental plots measured  $6.3 \times 5 \text{ m}^2$  with 0.5 m pathways

between adjacent plots. A medium maturity commercial hybrid maize variety (SC635, Seed Co<sup>®</sup>) was planted at  $0.75 \text{ m} \times 0.50 \text{ m}$  (inter- and intra-row spacing, respectively) in both the intercrop and sole crop. Four maize seeds were planted per planting hole and then thinned to two plants per hole at 3 weeks after crop emergence (WACE), giving a plant population of 53,333 maize plants  $\text{ha}^{-1}$ . Intercrops were planted at a seeding ratio of 1:2 maize/legume. The legumes were planted between maize plant rows at  $0.25 \text{ m} \times 0.10 \text{ m}$  (inter- and intra-row spacing, respectively). Silverleaf was planted at a seeding rate of  $2.5 \text{ kg ha}^{-1}$  while velvet bean and cowpea were each planted at a density of 215,000 plants  $\text{ha}^{-1}$  (Bryan and Materu 1987; CTA 2007).



**Figure 2.** Rainfall data (mm) for the two experimental seasons (2016/2017 and 2017/2018) for Hunyani farm in Chinhoyi.

### Trial management

Primary tillage was done by deep ploughing to incorporate plant residues into the soil, break the soil hard pan and kill weeds. This was followed by secondary tillage using a disc harrow for further breaking down of the large clods. Planting holes were established for both maize and legumes using hand hoes. In both seasons, the planting dates were determined by the onset of the rain season and were done on 21st December

**Table 1.** Treatment combinations of a 4 × 4 factorial experiment testing the effect of four fertiliser treatments and four cropping systems during the 2016/2017 and 2017/2018 cropping seasons at Hunyani farm, Chinhoyi, Zimbabwe.

Treatment combinations	
Fertiliser regime	Cropping system
150 kg ha <sup>-1</sup> Comp D + 150 kg ha <sup>-1</sup> AN	Sole maize
150 kg ha <sup>-1</sup> comp D + 150 kg ha <sup>-1</sup> AN	Maize-Silverleaf desmodium
150 kg ha <sup>-1</sup> comp D + 150 kg ha <sup>-1</sup> AN	Maize-Velvet bean
150 kg ha <sup>-1</sup> comp D + 150 kg ha <sup>-1</sup> AN	Maize-Cowpea
100 kg ha <sup>-1</sup> SSP	Sole maize
100 kg ha <sup>-1</sup> SSP	Maize-Silverleaf desmodium
100 kg ha <sup>-1</sup> SSP	Maize-Velvet bean
100 kg ha <sup>-1</sup> SSP	Maize-Cowpea
200 kg ha <sup>-1</sup> SSP	Sole maize
200 kg ha <sup>-1</sup> SSP	Maize-Silverleaf desmodium
200 kg ha <sup>-1</sup> SSP	Maize-Velvet bean
200 kg ha <sup>-1</sup> SSP	Maize-Cowpea
No fertiliser	Sole maize
No fertiliser	Maize-Silverleaf desmodium
No fertiliser	Maize-Velvet bean
No fertiliser	Maize-Cowpea

Note: Comp D denotes compound D fertiliser (7% N: 8% P<sub>2</sub>O<sub>5</sub>: 7% K<sub>2</sub>O), AN denotes ammonium nitrate (34.5% N), SSP denotes single super phosphate (17.5% P<sub>2</sub>O<sub>5</sub>).

2016 for the 2016/2017 cropping season and on the 5th of January 2018 for the 2017/2018 season. Compound D and SSP as basal fertilisers were applied at a depth of 5–10 cm below the seed before planting the maize and legumes. In those fertiliser treatments where maize was top-dressed with AN, the fertiliser was side-dressed 5–10 cm from each plant at 3 WACE. Weeding was done manually using a hoe, one day after collection of weed biomass data at 3, 6 and 9 WACE, during each cropping season.

### Data collection

During the 2017/2018 cropping season, soil sampling was done before land preparation on the 14th of December 2017. A total of 10 samples were collected from the entire field using the zig-zag sampling approach at a depth of 0–20 cm (Nyamangara et al. 2000). The collected soil samples were air-dried, crushed to pass through a 2 mm sieve and were stored in paper bags at room temperature. The samples were then analysed for particle size distribution (hydrometer method), pH (0.01 M CaCl<sub>2</sub> method), total N using the incubation technique (Keeney et al. 1982), bicarbonate P using the resin membrane technique (Byrne 1979), as well as exchangeable K, Ca and Mg. Concentrations of Ca and Mg were determined by atomic absorption spectrophotometry whilst K was determined by atomic emission spectrophotometry (Anderson and Ingram 1993; Okalebo et al. 2002). This procedure was repeated at the end of the 2017/2018 season after all experiments were harvested; however, a sample of five sub-samples

was collected within each experimental plot to make a composite sample.

Forage legume and above-ground weed biomass data were collected using destructive sampling at 3, 6 and 9 WACE during each cropping season. A 1 m × 1 m quadrant was thrown in each plot, and the weed and legume biomass were individually determined by cutting all weed and legume plants in the quadrant at ground level. The collected samples were packed in separate brown paper bags, oven-dried at 85°C for 48 h, and then dry mass was determined using a digital scale. The greater proportion of the forage legume plants in the plots was left for final yield determination.

100-grain weight (g) and grain yield (kg ha<sup>-1</sup>) were measured in both cropping seasons; however, during the 2017/2018 cropping season, the number of barren plants per hectare, number of kernels per ear and ear weight (g) were measured as additional maize parameters. All the maize yield parameters were determined at the crop's physiological maturity from a net plot of 5 m × 4 m after discarding two plants from either side of the plot. The number of barren plants was determined by counting the number of plants without ears in each plot. Maize cobs were then harvested manually, shelled and the grain yield per plot was determined using a digital scale. Ear mass and number of kernels per ear were determined from five randomly selected ears per plot. A random sample of 100 grains from each plot was taken and weighed to determine the weight of 100 grains. Grain moisture content was measured on a random sample of grain from each plot and used to standardize 100-grain weight and maize grain yield ha<sup>-1</sup> to 12.5% moisture content before statistical analysis.

The potential contribution to total inorganic nitrogen in the soil by the forage legumes (cowpea, silverleaf and velvet bean) was determined by finding the product of the legume biomass and a multiplication factor of two (Unkovich et al. 2008). For cowpea, it was determined by finding the product of the legume biomass and a multiplication factor of 1.4 (Unkovich et al. 2008).

### Data analysis

Pre- and post-harvest data for both maize and forage legumes for the two cropping seasons followed a normal distribution and required no transformation. Year effect was significant ( $P < 0.05$ ) on all response variables, and the results were, therefore, presented separately for each year. The data were subjected to analysis of variance using Genstat Release 18th edition VSN, INTERNATIONAL (2014). Where statistical significance was detected, mean separation was done using  $\pm$  standard error of difference ( $\pm$ s.e.d) at  $P \leq 0.05$ .

## Results

### Weed biomass

During the 2016/2017 cropping season, the cropping system (sole maize and maize-legume intercrops) significantly affected ( $P < 0.05$ ) weed biomass at 6 WACE but not at 3 and 9 WACE (Table 2). In particular, at 6 WACE, weed biomass declined in the intercrop systems by magnitudes of 57.3% (maize-silverleaf) to 67.5% (maize-cowpea) relative to the sole maize treatment. During the 2017/2018 cropping season, weed biomass was significantly affected ( $P < 0.05$ ) by cropping systems treatments across all sampling times (Table 2). At 9 WACE, intercropping maize with velvet bean reduced weed biomass by an average of 79.3% compared to maize-silverleaf intercropping and sole maize. In the 2016/2017 cropping season, the fertiliser regime had no significant effect ( $P > 0.05$ ) on weed biomass throughout the sampling period (Table 2). However, in the 2017/2018 cropping season, fertiliser regime had a significant effect ( $P < 0.05$ ) on weed biomass only at 6 WACE. There was a significant interaction ( $P > 0.05$ ) between cropping system and fertiliser regime on weed biomass at 3 and 6 WACE (Table 2).

The interaction between cropping system and fertiliser regime on weed biomass at 3 WACE revealed that, in the maize-cowpea cropping system, weed biomass was 181.2% higher in plots that were treated with 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN than in plots that had no fertiliser application, indicating that NPK fertilisers plus AN stimulated weed emergence and growth (Figure 3(a)). For the maize-silverleaf crop-

ping system, application of 100 kg ha<sup>-1</sup> SSP reduced weed biomass by 43.9% compared to no-fertiliser application. However, in the maize-velvet bean intercrop, application of 100 kg ha<sup>-1</sup> SSP resulted in a 435.8% increase in weed biomass relative to the no-fertiliser treatment. Finally, weed biomass in the sole maize system declined by an average of 55.9% in the 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN treatment compared to 100 kg ha<sup>-1</sup> and 200 kg ha<sup>-1</sup> SSP. Later on at 6 WACE, significant interaction effects ( $P < 0.05$ ) of cropping system and fertiliser regime showed that application of 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN in the maize-cowpea intercrop increased weed biomass by almost six times compared to either no fertiliser or application of 100 kg ha<sup>-1</sup> of SSP (Figure 3(b)). On the other hand, the application of 100 kg ha<sup>-1</sup> of SSP under sole maize almost trebled the amount of weed biomass compared to all other fertiliser regimes.

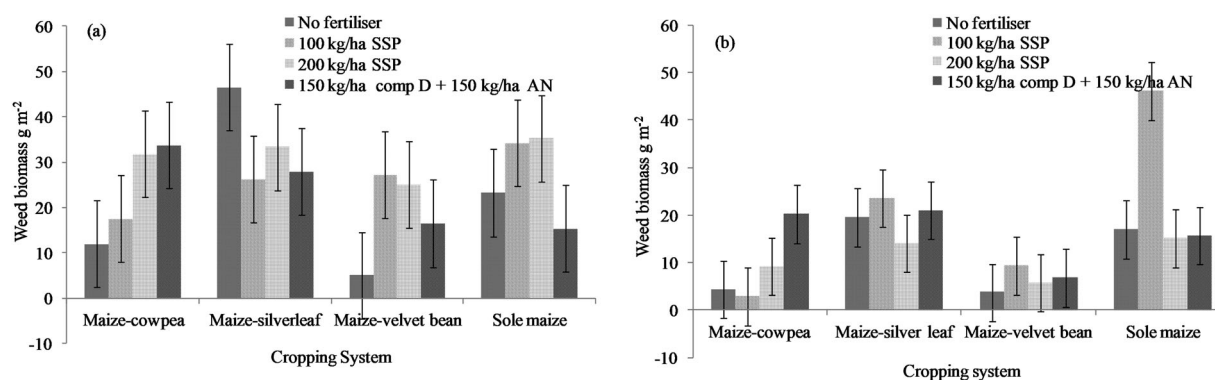
### Forage legume biomass

The cropping system (sole maize and maize-legume intercrops) significantly affected ( $P < 0.05$ ) legume biomass across all sampling times during the 2016/2017 and 2017/2018 cropping seasons (Table 3). In the 2016/2017 cropping season, legume biomass during the three sampling times averaged 106.2% higher in the maize-cowpea intercrop compared to maize-velvet bean and maize-silverleaf intercrops, respectively (Table 3). During the 2017/2018 cropping season, the collected forage legume biomass showed a similar trend as was observed during the previous season.

**Table 2.** Effect of different cropping system and fertiliser regime on weed biomass during the 2016/2017 and 2017/2018 cropping seasons at Hunyani farm in Chinhoyi, Zimbabwe.

Treatment factors	Weed biomass g m <sup>-2</sup>					
	2016/2017			2017/2018		
	3WACE	6WACE	9WACE	3WACE	6WACE	9WACE
Effect of cropping system						
Sole maize	49.20	19.50 <sup>b</sup>	29.80	27.02 <sup>ab</sup>	23.47 <sup>b</sup>	7.23 <sup>b</sup>
Maize-silverleaf	63.30	8.33 <sup>a</sup>	24.10	33.49 <sup>b</sup>	19.53 <sup>b</sup>	7.54 <sup>b</sup>
Maize-cowpea	66.60	6.33 <sup>a</sup>	24	23.74 <sup>a</sup>	9.16 <sup>a</sup>	3.79 <sup>ab</sup>
Maize-velvet bean	66.20	6.92 <sup>a</sup>	27.20	18.47 <sup>a</sup>	6.42 <sup>a</sup>	1.53 <sup>a</sup>
<i>P</i> -value	0.576	<.001	0.120	0.024	<0.001	0.005
±sed	14.170	2.519	2.910	4.778	3.035	1.848
Effect of fertiliser regime						
No fertiliser	69.50	10	26	21.70	11.14 <sup>a</sup>	6.46
100 kg ha <sup>-1</sup> SSP	52.50	9.52	26.20	26.31	20.45 <sup>b</sup>	5.65
200 kg ha <sup>-1</sup> SSP	73.60	11	28.10	31.35	11.05 <sup>a</sup>	4.68
150 kg ha <sup>-1</sup> D + 150 kg ha <sup>-1</sup> AN	49.60	10.67	25.30	23.36	15.93 <sup>ab</sup>	3.30
<i>P</i> -value	0.252	0.925	0.799	0.210	0.009	0.368
± sed	14.170	2.519	2.890	4.778	3.035	1.848
Fertiliser regime*cropping system interaction						
<i>P</i> -value	0.108	0.825	0.701	0.031	<0.001	0.294
±sed	28.340	5.038	5.780	9.556	6.071	3.697

Note: Comp D denotes compound D fertiliser (7% N; 8% P<sub>2</sub>O<sub>5</sub>; 7% K<sub>2</sub>O), AN denotes ammonium nitrate (34.5% N), SSP denotes single super phosphate (17.5% P<sub>2</sub>O<sub>5</sub>); WACE denotes weeks after crop emergence. For each treatment factor, mean values with the same letter in the same column are significantly different at  $P \leq 0.05$ .



**Figure 3.** Interaction between fertiliser regime and cropping system on weed biomass at (a) 3 WACE and (b) 6 WACE, during the 2017/2018 cropping season at Hunyani farm in Chinhoyi, Zimbabwe. Error bars are  $\pm$  standard error of difference (SED) for the comparison of fertiliser regime means within and across cropping system treatments.

Legume biomass was always greater (average: 108.7%) in the maize-cowpea intercrop than all other cropping systems except at 9 WACE when the maize-velvet bean intercrop produced 58.2% more biomass than the maize-silverleaf intercrops.

There was no significant fertiliser regime effect ( $P > 0.05$ ) on legume biomass during the 2016/2017 cropping season (Table 3). During the 2017/2018 cropping season, legume biomass showed a significant response ( $P < 0.05$ ) to fertiliser treatment only at 3 WACE. Furthermore, there was a significant interaction effect of cropping system  $\times$  fertiliser regime ( $P < 0.05$ ) on legume biomass at 3 WACE (Figure 4). In the maize-cowpea cropping system, legume biomass declined by an average of 33.8% when 150 kg ha<sup>-1</sup> of compound D + 150 kg ha<sup>-1</sup> of AN was applied relative to all other fertiliser regime treatments (Figure 4).

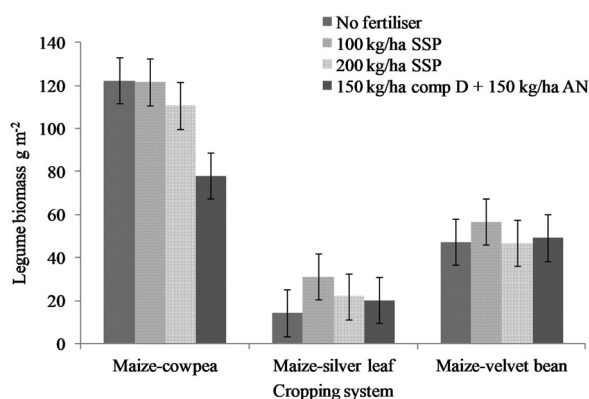
### Maize grain yield and maize grain parameters

The cropping system had a significant effect ( $P < 0.05$ ) on maize grain yield, number of barren plants ha<sup>-1</sup>, number of kernels per ear, 100-grain weight and ear weight in this study. Maize-velvet bean intercrop had the lowest maize grain yield, number of kernels per ear, 100-grain weight, ear weight and the highest number of barren plants showing that velvetleaf was the most competitive forage legume when intercropped with maize. Maize-silverleaf had the least (11,991) number of barren maize plants ha<sup>-1</sup>. Moreover, maize-cowpea intercrop and sole maize had statistically similar numbers of barren plants per hectare (14,954 and 14,074, respectively). The number of barren plants ha<sup>-1</sup> showed a significant ( $P < 0.05$ ) response to fertiliser regime treatments, increasing from 12176 to 19213 ha<sup>-1</sup>

**Table 3.** Effect of different cropping system and fertiliser regime on legume biomass during the 2016/2017 and 2017/2018 cropping seasons at Hunyani farm, Zimbabwe.

Treatment factors	Legume biomass (g m <sup>-2</sup> )					
	2016/2017			2017/2018		
	3WACE	6WACE	9WACE	3WACE	6WACE	9WACE
Effect of cropping system						
Maize-silverleaf	20.40 <sup>a</sup>	113 <sup>a</sup>	231.20 <sup>a</sup>	21.91 <sup>a</sup>	124 <sup>a</sup>	134 <sup>a</sup>
Maize-cowpea	48.10 <sup>b</sup>	231 <sup>b</sup>	359.50 <sup>c</sup>	108.24 <sup>c</sup>	243 <sup>c</sup>	158 <sup>ab</sup>
Maize-velvet bean	19.80 <sup>a</sup>	85 <sup>a</sup>	282.90 <sup>b</sup>	49.99 <sup>b</sup>	183 <sup>b</sup>	212 <sup>b</sup>
<i>P</i> -value	<0.001	<0.001	<0.001	<0.001	<0.001	0.015
$\pm$ sed	6.530	25.300	9.340	5.381	26.800	35.100
Effect of fertiliser regime						
No fertiliser	24.40	175	279.20	61.32 <sup>ab</sup>	187	208
100 kg ha <sup>-1</sup> SSP	38.10	137	294.70	69.86 <sup>b</sup>	177	238
200 kg ha <sup>-1</sup> SSP	28.60	112	301.20	59.84 <sup>ab</sup>	211	242
150 kg ha <sup>-1</sup> comp D + 150 kg ha <sup>-1</sup> AN	26.70	148	289.70	49.17 <sup>a</sup>	158	219
<i>P</i> -value	0.306	0.208	0.249	0.020	0.399	0.819
$\pm$ sed	7.54	29.2	10.79	6.213	30.9	40.6
Fertiliser regime*cropping system interaction						
<i>P</i> -value	0.593	0.553	0.063	0.044	0.805	0.976
SED	13.050	50.500	18.680	10.762	53.600	70.300

Note: Comp D denotes compound D fertiliser (7% N: 8% P<sub>2</sub>O<sub>5</sub>: 7% K<sub>2</sub>O), AN denotes ammonium nitrate (34.5% N), SSP denotes single super phosphate (17.5% P<sub>2</sub>O<sub>5</sub>); WACE denotes weeks after crop emergence. For each treatment factor, mean values with the same letter in the same column are significantly different at  $P \leq 0.05$ .



**Figure 4.** Effect of different fertiliser regime and cropping system on legume biomass at 3 WACE during the 2017/2018 cropping season at Hunyani farm, Zimbabwe. Error bars are  $\pm$  standard error of difference (SED) for the comparison of fertiliser regime means within and across cropping system treatments.

in the order compound D + 150 kg ha<sup>-1</sup> of AN < 200 kg ha<sup>-1</sup> SSP < 100 kg ha<sup>-1</sup> SSP and no fertiliser. However, there was no significant cropping system  $\times$  fertiliser regime interaction ( $P > 0.05$ ) on the number of maize barren plants per hectare.

Cropping system (sole maize and maize-legume intercrops) and fertiliser regime significantly affected ( $P < 0.05$ ) the number of kernels ear<sup>-1</sup> (Table 4). The number of kernels ear<sup>-1</sup> significantly increased from 298.55 in the maize-velvet bean intercrop to 452.41 in sole maize. For fertiliser regime, the least number of kernels ear<sup>-1</sup> (359.07) was recorded in plots that received 100 kg ha<sup>-1</sup> SSP and the highest (457.10) was in plots that received 150 kg compound D + 150 kg AN. There was no significant interaction ( $P > 0.05$ ) between fertiliser regime and cropping system on the kernel number ear<sup>-1</sup>.

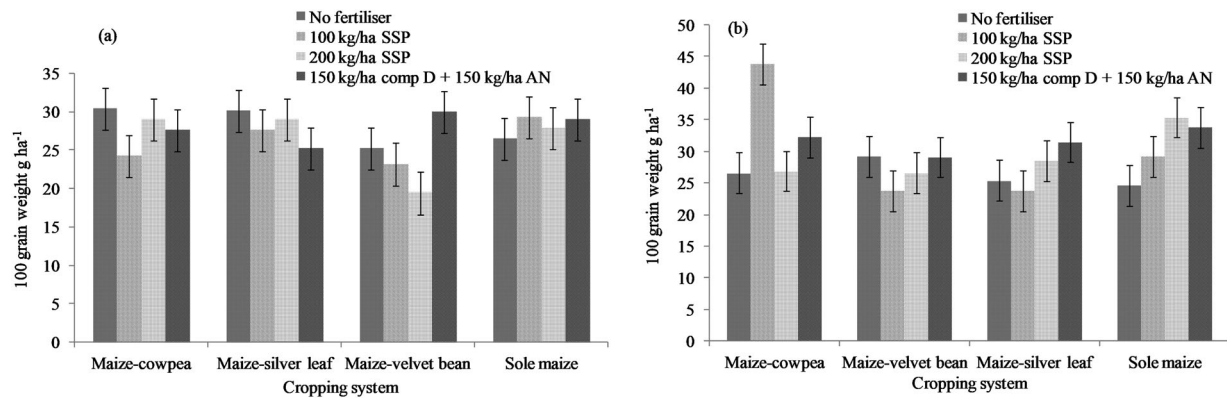
The cropping system (sole maize and maize-legume intercrops) and fertiliser regime had significant effects ( $P < 0.05$ ) on maize ear weight (Table 4). Relative to sole maize, maize-legume intercropping systems reduced maize ear weight by 10–15.1% (maize-silverleaf and maize-cowpea) and 46% (maize-velvet bean). In terms of fertiliser regime, no-fertiliser and SSP application at 100 and 200 kg ha<sup>-1</sup> had similar effects on maize ear weight. However, the application of the 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN resulted in a 31.3–38.4% significant ( $P < 0.05$ ) increase in ear weight relative to all other fertiliser regimes. There was no significant cropping system  $\times$  fertiliser regime interaction effect ( $P > 0.05$ ) on ear weight.

The cropping system (sole maize and maize-legume intercrops) had a significant effect ( $P < 0.05$ ) on the maize 100-grain weight during both the 2016/2017 and 2017/2018 cropping seasons (Table 4). During the two cropping seasons (2016/2017 and 2017/2018), the fertiliser regime had no significant effect ( $P > 0.05$ ) on the 100-grain weight. There were significant interaction effects ( $P < 0.05$ ) of fertiliser regime  $\times$  cropping system on the 100-grain weight during the 2016/2017 and 2017/2018 seasons. In 2016/2017, 100 kg ha<sup>-1</sup> SSP treated plots produced the least 100-grain weight in maize-cowpea intercrop compared to other fertiliser regimes while in the maize-velvet bean cropping system, 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN resulted in higher 100-grain weight than SSP application (Figure 5(a)). However, during the 2017/2018 cropping season, 100 kg ha<sup>-1</sup> SSP treated plots contained higher 100-grain weight in the maize-cowpea intercrop compared to other fertiliser regimes (Figure 5(b)). During this same cropping season (2016/2017), the application of either 200 kg ha<sup>-1</sup> SSP or 150 kg ha<sup>-1</sup> compound D

**Table 4.** Effect of cropping system and fertiliser regime on maize yield parameters during the 2016/2017 and 2017/2018 cropping seasons at Hunyani farm, Zimbabwe.

Treatment factors	No. of barren plants ha <sup>-1</sup>	No. of Kernels ear <sup>-1</sup> 2017/2018	Ear weight (g)	100 grain weight (g)		Grain yield (kg ha <sup>-1</sup> )	
				2016/2017	2017/2018	2016/2017	2017/2018
<b>Cropping system</b>							
Sole maize	14074 <sup>ab</sup>	452.41 <sup>c</sup>	164.56 <sup>c</sup>	31.25 <sup>b</sup>	28.13 <sup>b</sup>	4179.18 <sup>c</sup>	2780.99 <sup>c</sup>
Maize-silverleaf	11991 <sup>a</sup>	448.75 <sup>c</sup>	148.15 <sup>b</sup>	27.58 <sup>a</sup>	27.95 <sup>b</sup>	3891.35 <sup>c</sup>	3112.59 <sup>c</sup>
Maize-cowpea	14954 <sup>b</sup>	403.46 <sup>b</sup>	139.69 <sup>b</sup>	32.83 <sup>b</sup>	27.76 <sup>b</sup>	3230.42 <sup>b</sup>	2000.12 <sup>b</sup>
Maize-velvet bean	25093 <sup>c</sup>	298.55 <sup>a</sup>	88.92 <sup>a</sup>	27.58 <sup>a</sup>	24.43 <sup>a</sup>	1940.77 <sup>a</sup>	659.63 <sup>a</sup>
<i>P</i> -value	<0.001	<0.001	<0.001	0.017	0.029	<0.001	<0.001
$\pm$ sed	1432.8	18.65	6.834	1.884	1.375	302.809	253.977
<b>Fertiliser regime</b>							
No fertiliser	18843 <sup>c</sup>	383.36 <sup>ab</sup>	123.60 <sup>a</sup>	27.00	28.01	3127.53	1817.12 <sup>a</sup>
100 kg ha <sup>-1</sup> SSP	19213 <sup>c</sup>	359.07 <sup>a</sup>	121.52 <sup>a</sup>	30.58	26.03	3548.85	1863.53 <sup>a</sup>
200 kg ha <sup>-1</sup> SSP	15880 <sup>b</sup>	403.64 <sup>b</sup>	128.02 <sup>a</sup>	29.83	26.31	3211.97	2040.22 <sup>a</sup>
150 comp D+ 150 AN	12176 <sup>a</sup>	457.10 <sup>c</sup>	168.19 <sup>b</sup>	31.83	27.93	3353.37	2832.46 <sup>b</sup>
<i>P</i> -value	<0.001	<0.001	<0.001	0.091	0.335	0.536	<0.001
$\pm$ sed	1432.80	18.650	6.834	1.884	1.375	302.809	253.977
<b>Fertiliser regime <math>\times</math> cropping system interaction</b>							
<i>P</i> -value	0.607	0.953	0.149	0.002	0.021	0.981	0.900
$\pm$ sed	2865.60	37.306	13.668	36.050	2.749	605.617	507.954

Note: Comp D denotes compound D fertiliser (7% N; 8% P<sub>2</sub>O<sub>5</sub>; 7% K<sub>2</sub>O), AN denotes ammonium nitrate (34.5% N), SSP denotes single super phosphate (17.5% P<sub>2</sub>O<sub>5</sub>); For each treatment factor, mean values with the same letter in the same column are significantly different at  $P \leq 0.05$ .



**Figure 5.** Effect of different fertiliser regime and cropping system on 100-grain weight during the (a) 2016/2017 and (b) 2017/2018 cropping seasons at Hunyani farm in Chinhoyi, Zimbabwe. Error bars are  $\pm$  standard error of difference (SED) for the comparison of fertiliser regime means within and across cropping system treatments.

+ 150 kg ha<sup>-1</sup>AN in sole maize resulted in a higher 100-grain weight.

There was a significant cropping system (sole maize and maize-legume intercrops) effect ( $P < 0.05$ ) on maize grain yield in both 2016/2017 and 2017/2018 cropping seasons (Table 4). Maize grain yield was highest in the maize-silverleaf (3891.35 kg ha<sup>-1</sup>) and sole maize (4179.18) cropping systems, followed by the maize-cowpea (3230.42 kg ha<sup>-1</sup>) and maize-velvet bean (1940.77 kg ha<sup>-1</sup>) cropping systems. The trend was exactly similar during the 2017/2018 cropping season, although the grain yield was now lower, ranging from 659.63 kg ha<sup>-1</sup> in maize-velvet bean to 3112.59 kg ha<sup>-1</sup> in maize-silverleaf cropping systems. Furthermore, the fertiliser regime had no significant effect ( $P > 0.05$ ) on maize grain yield during the 2016/2017 cropping season but had significant effects ( $P < 0.05$ ) during the 2017/2018 cropping season. The application of 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup>AN fertiliser regime produced a higher maize grain yield (2832.46 kg ha<sup>-1</sup>) than the other fertiliser treatments (1817.12–2040.22 kg ha<sup>-1</sup>). There was no significant fertiliser regime  $\times$  cropping system interaction effect ( $P > 0.05$ ) on maize grain yield in both cropping seasons.

### Soil fertility

The soils at the Chinhoyi University of Technology Hunyani Farm were found to be lacking in most of the mineral nutrients based on samples that were collected and tested before the onset of the 2017/2018 experiment. Particularly, the pH of the soil was low, and the soil was deficient in key macronutrients (N, P and K) that are required to support plant growth (Table 5). However, the key micronutrients (calcium and magnesium) were adequate for crop production.

During the 2017/2018 cropping season, the cropping system had significant effects ( $P < 0.05$ ) on resin-extractable P<sub>2</sub>O<sub>5</sub>, but had no significant effect ( $P > 0.05$ ) on all other soil fertility parameters. Except for resin-extractable P<sub>2</sub>O<sub>5</sub>, potential mineral nitrogen, potassium, calcium and magnesium exhibited no significant response to the fertiliser regime.

Out of the six soil fertility parameters, significant cropping system  $\times$  fertiliser regime interaction effects ( $P < 0.05$ ) were observed on soil mineral nitrogen and resin-extractable P<sub>2</sub>O<sub>5</sub> during the 2017/2018 cropping season (Table 6). The application of 100 kg ha<sup>-1</sup> of SSP fertiliser in maize-silverleaf cropping system resulted in higher mineral N (78 mg kg<sup>-1</sup>) than all other fertiliser regimes (Figure 6). The significant response of mineral nitrogen to fertiliser regime was absent in all other cropping systems (Table 6).

During the 2017/2018 cropping season, a significant effect ( $P < 0.05$ ) of fertiliser regime on resin-extractable P<sub>2</sub>O<sub>5</sub> was observed across all cropping system treatments (Figure 7). The 200 kg ha<sup>-1</sup> SSP fertiliser regime resulted in higher (25.8–32.8 mg kg<sup>-1</sup>) resin-extractable P<sub>2</sub>O<sub>5</sub> than other fertiliser regime treatments (9–19 mg kg<sup>-1</sup>) across maize-legume intercrops. It is important to note that the application of 100 kg ha<sup>-1</sup> SSP in the maize-

**Table 5.** Soil pH and nutrient status before the onset of the 2017/2018 cropping season at Hunyani farm in Chinhoyi, Zimbabwe.

Soil parameter	Mean	Comment*
Texture	MgSCL	Medium-grained sand clay loam
Soil pH (0.01 M CaCl <sub>2</sub> )	5.28	Medium acid
KCl-N after incubation (mg kg <sup>-1</sup> )	22.20	Low
Resin-extractable P <sub>2</sub> O <sub>5</sub> (mg kg <sup>-1</sup> )	9.90	Deficient
Exchangeable K (meq/100 g soil)	0.18	Acutely deficient
Exchangeable Ca (meq/100 g soil)	10.23	Adequate
Exchangeable Mg (meq/100 g soil)	9.46	Adequate

\*Comments adapted from Nyamangara et al. (2000).

**Table 6.** Effect of different cropping system and fertiliser regime on soil fertility parameters during 2017/2018 cropping seasons at Hunyani farm in Chinhoyi, Zimbabwe.

	2017/2018					
	pH (0.01M CaCl <sub>2</sub> )	Mineral Nitrogen mg kg <sup>-1</sup>	Resin-extract P <sub>2</sub> O <sub>5</sub> mg kg <sup>-1</sup>	Potassium	Calcium meq 100 g <sup>-1</sup> soil	Magnesium
<b>Cropping system</b>						
Sole maize	5.44	48.30	14.90 <sup>a</sup>	0.19	15.00	10.72
Maize-silverleaf	5.42	54.90	25.70 <sup>b</sup>	0.20	16.90	11.14
Maize-cowpea	5.47	51.50	16.50 <sup>a</sup>	0.18	12.80	10.55
Maize-velvet bean	5.23	48.10	16.90 <sup>a</sup>	0.20	12.90	11.64
<i>P</i> -value	0.576	0.479	0.002	0.521	0.587	0.232
±sed	0.131	4.980	2.030	0.014	2.430	0.398
<b>Fertiliser regime</b>						
No fertiliser	5.34	46.40	12.40 <sup>a</sup>	0.18	14.50	10.62
100 kg ha <sup>-1</sup> SSP	5.21	54.60	19.20 <sup>b</sup>	0.20	12.00	11.43
200 kg ha <sup>-1</sup> SSP	5.50	50.10	24.80 <sup>c</sup>	0.19	15.50	11.16
150 kg ha <sup>-1</sup> comp D + 150 kg ha <sup>-1</sup> AN	5.51	51.80	17.60 <sup>b</sup>	0.20	14.50	10.83
<i>P</i> -value	0.309	0.428	0.001	0.658	0.697	0.490
±sed	0.130	4.980	2.030	0.014	2.430	0.398
<b>Fertiliser regime × cropping system interaction</b>						
<i>P</i> -value	0.306	0.018	0.040	0.859	0.139	0.371
±sed	0.262	9.950	4.060	0.028	4.860	0.797

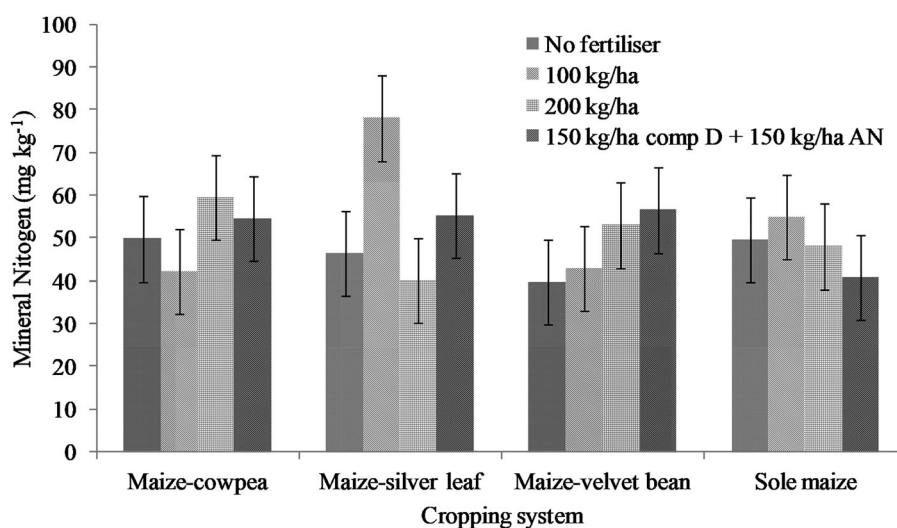
silverleaf intercrop had similar effects with increasing the rate to 200 kg ha<sup>-1</sup> of SSP. In contrast, for sole maize, resin-extractable P<sub>2</sub>O<sub>5</sub> was significantly higher ( $P < 0.05$ ) in plots that received 150 kg ha<sup>-1</sup> of compound D + 150 kg ha<sup>-1</sup> of AN relative to all other fertiliser regimes.

## Discussion

### Weed biomass

The maize-legume intercrops suppressed weed growth by magnitudes of 53–80% relative to sole maize (Table 2) starting from 3 WACE in 2016/17 and 2017/18 cropping seasons. This was most probably because the

combined foliage of maize and legumes provided rapid and complete ground cover which reduced weed emergence and growth more effectively than in sole maize. Weed emergence is reduced because most small-seeded weed species require exposure to white light for seed germination and light that passes through green foliage is far-red rich which is generally inhibitory to weed germination (Demotes-Mainard et al. 2016; Humphries et al. 2018). Elsalahy et al. (2019) and Su et al. (2018) related the reduction in weed biomass to reduced photosynthetically active radiation transmittance to the weeds as a result of the greater interception of incoming radiation by the combined maize-legume foliage.


**Figure 6.** Interaction between fertiliser regime and cropping system on mineral nitrogen (mg kg<sup>-1</sup>) during 2017/2018 cropping season at Hunyani farm in Chinhoyi, Zimbabwe. Error bars are ± standard error of difference (SED) for the comparison of fertiliser regime means within and across cropping system treatments.

The results showed a significant interaction effect of cropping system and fertiliser regime on weed biomass (Figures 3(a,b)). During early maize growth, application of SSP particularly at a higher rate of  $200 \text{ kg ha}^{-1}$ , favoured increased weed biomass production in the maize-cowpea and maize-velvet bean intercrops but weed biomass was reduced by application of  $100 \text{ kg ha}^{-1}$  of SSP in the maize-silverleaf intercrop compared to the unfertilised control plots (Figure 3a). These results suggest that silverleaf requires some additional P at the early stages of growth to be able to smother weeds. Similarly, Cook et al. (2005) also reported that silverleaf needs high soil fertility and that P, S and K must be applied before sowing for vigorous growth. Furthermore, there was increased weed biomass in plots that were treated with  $150 \text{ kg ha}^{-1}$  compound D +  $150 \text{ kg ha}^{-1}$  AN compared to the no-fertiliser treatment under maize-cowpea cropping system (Figures 3(a,b)). We hypothesize that the response of weeds to inorganic fertiliser application in the maize-cowpea cropping system may be attributed to inhibition of the nitrogen fixation process (product inhibition) which limited N availability, dry matter production and resulted in a small cowpea plant canopy (Jiri and Mafongoya 2018). Based on similar findings, Dekker (2009) concluded that fertiliser application increases resources per unit area, which are more efficiently extracted by weeds compared to crops, which provide a competitive advantage towards the growth and development of weeds. Notably, when maize was grown as a sole crop, weed biomass was almost trebled by the application of  $100 \text{ kg ha}^{-1}$  SSP, suggesting that in this monoculture cropping system, P had the potential to support vigorous and competitive weed growth at the expense of crop growth and yield.

### Forage legume biomass

Forage legume biomass was 17.9–394% higher in the maize-cowpea intercrop than all the other cropping systems during the 2016/2017 and 2017/2018 cropping seasons (Table 3). The rapid growth and high biomass production that was recorded for cowpea as shown in Table 3 will most likely confer positive effects on soil organic matter accumulation and thus improve soil fertility status. Compared to cowpea, velvet bean and silverleaf appeared to have slower growth rates and dry matter accumulation. The results of this present study also showed a reduction in forage legume biomass in the maize-cowpea cropping system that received  $150 \text{ kg ha}^{-1}$  compound D +  $150 \text{ kg ha}^{-1}$  AN. These results are similar to the findings of Kermah et al. (2017), who also found that in maize-cowpea intercrop,

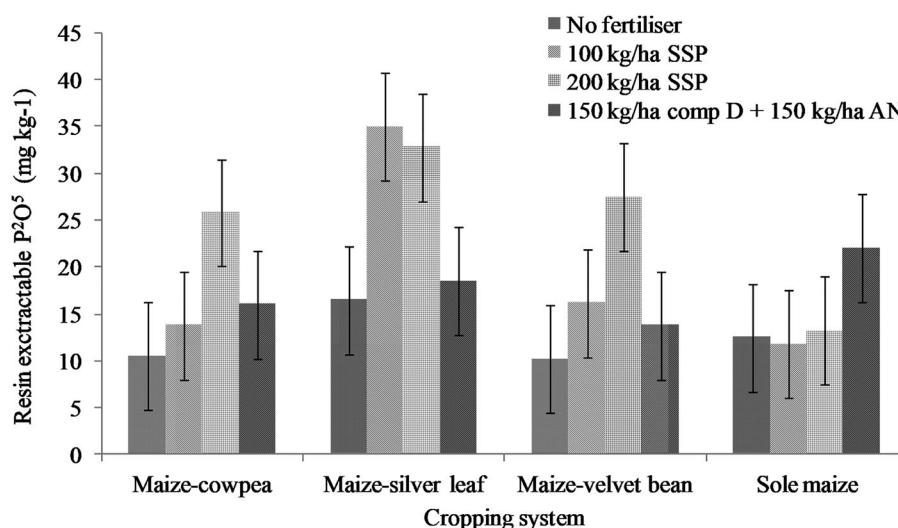
an increase in fertiliser use results in increased maize competitiveness, thus reduced cowpea biomass. Jiri and Mafongoya (2018) assert that at varying fertiliser application rates, there is a reduction in nitrogen fixation rate thus, suppressing dry matter production and allocation toward biomass accumulation.

### Maize grain yield and maize grain parameters

The highest number of maize barren plants per hectare were recorded in maize-velvet bean cropping system (Table 4). This was probably due to high competition for the available resources (light, water and nutrients) between maize and velvet bean hence disrupting allometric allocation toward the development of reproductive parts of the maize crop (Kermah et al. 2017). Velvet bean crop has an indeterminate climbing growth habit that chokes maize plants thus disrupting ear development. Due to the fibrous root system of maize crop, the weight of velvet bean plants may overcome the stability of the crop thus resulting in lodging of the maize crop during its reproductive growth stage (Chikoye and Ekeleme 2001). This is in contrast to what was observed under cowpea and silverleaf cropping systems.

The lowest number of barren maize plants in plots that received  $150 \text{ kg ha}^{-1}$  D +  $150 \text{ kg ha}^{-1}$  AN suggest that besides this treatment, all the other fertiliser regime treatments failed to provide adequate nutrients for kernel development (Shen et al. 2018). This can be attributed to the fact that the application of nitrogen-based fertilisers promotes the growth and development of maize kernels (through the promotion of photosynthesis as a result of cell expansion, growth and enzymatic development). Increased photosynthesis will result in more dry matter production thus the development of the economic yield (Mashingaidze 2004).

Intercropping maize with velvet bean reduced the number of kernels  $\text{ear}^{-1}$  by magnitudes of 26–33.7% relative to all other cropping systems. These results as presented in Table 4 show that velvet bean is a strong competitor, probably capable of extensive extraction of a large amount of nutrients from all areas around its root zone (Nielsen 2005). In addition, velvet bean shades the maize plant thus depriving them of radiation required for photosynthesis (Hauser et al. 2008). Reduction in the rate of photosynthesis leads to reduced dry matter production and partitioning of photo-assimilates to economic yield, (Mashingaidze 2004). However, Nielsen (2005) asserts that, to meet the demand of photo-assimilates by the reproductive parts, the maize crop reduces the number of kernels  $\text{ear}^{-1}$  in stressing conditions. The high number of maize kernels



**Figure 7.** Interaction between fertiliser regime and cropping system on resin-extractable P<sub>2</sub>O<sub>5</sub> (mg kg<sup>-1</sup>) during 2017/2018 cropping season at Hunyani farm in Chinhoyi, Zimbabwe. Error bars are  $\pm$  standard error of difference (SED) for the comparison of fertiliser regime means within and across cropping system treatments.

per ear recorded in sole maize and maize-silverleaf cropping system agrees with the findings of Konlan et al. (2013) who reported that in some areas of the Savannah region, sole maize crops were more productive than intercrops when two or more rows of intercropped maize were alternated with the same number of a legume crop. In sole maize there was no competition for nutrients and light thus increasing the rate of nutrient utilisation and photosynthesis by the maize crop, hence the recorded high number of kernels ear<sup>-1</sup> (Konlan et al. 2013; Kermah et al. 2017). The bushy growth habits of the legumes most probably reduced evapotranspiration and maintained a moist soil environment in the understory of the maize-legume intercrops that sustained maize plant growth and yield formation in maize, in addition to BNF providing additional N to the maize crop. However, for velvet leaf, its high competitiveness for water, mineral nutrients and Photosynthetically Active Radiation (PAR) against maize negated this advantage, reducing kernel number and maize grain yield. This provides a steady water supply for maize, which is important for the physiological and biochemical reactions in plants that result in increased kernel number per plant (Cook et al. 2005).

The highest number of kernels ear<sup>-1</sup> recorded in the 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN fertiliser treatment (Table 4) may be attributed to the availability of nitrogen, a major nutrient for plant growth in relation to protein formation and cellular growth (McAllister et al. 2012). Thus, an increase in N availability often initiates vegetative growth and those processes that are associated with dry matter production, increasing photo-assimilate direction toward the development of

economic yield (Mashingaidze 2004; Nielsen 2005). In contrast, the number of kernels ear<sup>-1</sup> was reduced when only 100 kg ha<sup>-1</sup> SSP was applied, most likely because of nitrogen deficiency thus reducing plant growth. As a result of nitrogen deficiency, there was a reduced rate of photosynthesis and dry matter allocation to economic yield, hence a reduced number of kernels per ear (Silva et al. 2004).

The legume intercrops reduced maize ear weight, with a 46% reduction in the maize-velvet bean system (Table 4). Velvet bean is characterized by a dense root network which intensifies its nutrient scavenging ability providing nutrition for vegetative growth thus increasing competitive ability in terms of radiation, water and nutrients capture (Hodge 2004). This reduces nutrients available for uptake by the maize crop thus reducing plant biochemical reactions required for economic yield development (Silva et al. 2004). The average ear weight was higher in maize-silverleaf and maize-cowpea cropping systems than maize-velvet bean intercrop probably because silverleaf and cowpea have a determinate bush architecture hence have little competition for radiation (Cook et al. 2005). This canopy architecture maintains a favourable microclimate around the maize crop by reducing water loss through evaporation from the soil (Hartwig and Ammon 2002). Water is vital for all chemical reactions thus the microclimate around the maize crop ensures full microbial and biochemical reactions around and within the maize plant resulting in increased ear weight (Matusso et al. 2014). The highest ear weight obtained in the sole maize cropping system may be attributed to minimum competition for growth

resources within the environment particularly during the crop's reproductive stage (Konlan et al. 2013).

Furthermore, as shown in Table 4, the fertiliser regime influenced the ear weight of the maize crop, with non-nitrogen-based fertiliser treatments (no fertiliser, 100 kg ha<sup>-1</sup> SSP and 200 kg ha<sup>-1</sup> SSP fertiliser regimes) producing the lightest ears compared to the 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN fertiliser regime. This was possible because compound D and AN fertilisers provided sufficient nitrogen required for photosynthesis and dry matter production for the development of the ear (McAllister et al. 2012; Mohammed et al. 2015).

Compared to no-fertiliser application, the 100-grain weight was lower under 100 kg ha<sup>-1</sup> SSP in the maize-cowpea while in the maize-velvet bean cropping system, 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN resulted in a higher 100-grain weight than the SSP application (Figure 5(a)). Meanwhile, as illustrated in Figure 5 (b), application of 100 kg ha<sup>-1</sup> SSP in the maize-cowpea intercrop and application of either 200 kg ha<sup>-1</sup> SSP or 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN in sole maize during the 2017/2018 season increased the 100-grain weight of maize kernels. This may be largely due to increased dry matter allocation towards the development of the economic yield per unit time as a result of the decrease in kernel number per unit plant area (Shen et al. 2018). This is in contrast to the other intercropping systems in which the high number of kernels per unit plant area resulted in a greater distribution of dry matter across the greater area thus minimising dry matter allocation per unit grain (Nielsen 2005). Hence, the reduction in grain weight with increased kernel number. In addition, nitrogen retention capacity by velvet bean has been reported to be higher than that of cowpea and silverleaf (Jiri and Mafongoya 2018). In relation to these results, Mapiye et al. (2007) denoted that cowpea fixes nitrogen in response to its demand per unit time and space such that the crop is beneficial after having been ploughed in. As such it is assumed that during its developmental phases, it is of little benefit to the major crop thus low nitrogen release. The high 100-grain weight that was observed in sole maize plots treated with 150 kg ha<sup>-1</sup> of compound D and 150 kg ha<sup>-1</sup> of AN and those with 200 kg ha<sup>-1</sup> of SSP might have been as a result of enough supply of required nutrients. The 150 kg ha<sup>-1</sup> of compound D and 150 kg ha<sup>-1</sup> of AN contain nitrogen which is vital for cellular growth and development of kernels (McAllister et al. 2012). Also in maize-velvet bean plots treated with 150 kg ha<sup>-1</sup> of compound D and 150 kg ha<sup>-1</sup> of AN, there were reduced numbers of kernels probably signifying increased photo-assimilate being directed towards the development of the few kernels produced (Nielsen 2005).

Similar to its effects on the number of barren plants ha<sup>-1</sup>, intercropping maize with velvet bean resulted in a maize grain yield reduction of 51.7–77.5% relative to sole maize and maize-silverleaf intercrop (Table 4). This suggests that velvet bean is highly competitive with regards to capturing available growth resources, thus reducing the allometric allocation of photosynthates towards the reproductive parts of the maize crop (Kermah et al. 2017). The same results were shown by Gabastshele et al. (2012) who concluded that, among all factors causing yield reduction in intercrops compared to cereal sole cropping, competition for resources is the major factor affecting yield. The percentage of maize yield reduction was lowest when maize was intercropped with silverleaf, a forage legume that is known for its negative allelopathic effects on weed growth at certain crucial periods in crop development (FAO 2011).

Although no evidence of maize grain yield response to fertiliser treatments was observed in 2016/2017, the application of 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN fertiliser produced the highest maize grain yield in 2017/2018 (Table 4). Both compound D and AN contain nitrogen, a major structural component of all proteins, and is essential in the synthesis of enzymes required during photosynthesis (McAllister et al. 2012). As a result, it can be assumed that contrary to the non-N-based fertiliser treatment, the 150 kg ha<sup>-1</sup> compound D + 150 kg ha<sup>-1</sup> AN fertiliser regime supported the production of enzymes for carbohydrate synthesis and photo-assimilate production (Mashingaidze 2004; Nielsen 2005).

### Soil fertility

Soil pH remained unchanged before and after treatment application (Table 6). This agrees with Nyamapfene (1991) who asserts that during the early years of the establishment of interactive cropping systems the build-up of different pools of organic matter content are usually too low to alter key soil chemical properties such as pH, buffering capacity and cation exchange capacity. The soil pH (5.4) of the study area at the onset of the study was medium acid (Table 5). This pH range is not considered ideal for optimal nutrient availability for most crops including maize and the different established legumes (Shehu et al. 2018). Potential contribution to mineral nitrogen in the soil during the 2016/2017 cropping season was lower (453.6 g m<sup>-2</sup>) in the maize-velvet bean intercrop than in the maize-silverleaf (559.9 g m<sup>-2</sup>) and maize-cowpea (495.90 g m<sup>-2</sup>) intercrops. These results suggest that silverleaf and cowpea have higher N-fixing abilities than velvet bean.

The high mineral nitrogen observed in maize-silverleaf intercrop in which 100 kg ha<sup>-1</sup> SSP fertiliser was

applied (Figure 6) might be attributed to the increased fixation potential of N by silverleaf due to the availability of phosphorus in the soil. The addition of phosphorus to leguminous plants growing in poor soils increases the plants' nitrogen-fixing efficiency, and concomitantly, their nodulation and biomass production (Magadlela et al. 2016). This will in turn increase soil N when legumes are used as live mulch in cereal crops as N is excreted from legume roots and leached from leaves (Giller 2001). The significant interaction between cropping system and fertiliser regime (Figure 7) showed that resin-extractable  $P_2O_5$  was highest in the maize-silverleaf intercrop which received  $100 \text{ kg ha}^{-1}$  SSP and in maize-cowpea and maize-velvet bean that had  $200 \text{ kg ha}^{-1}$  of SSP. Havlin et al. (2016) indicated that in granitic derived soils, recycling of phosphorus was slow thus available P was increased by application of P-based fertiliser formulations. The results corroborate earlier findings by Sanginga and Woomer (2009) who observed that *Desmodium uncinatum* forms symbiotic relations with mycorrhizal fungi which recover P from scarce reserves and increase its availability in the soil. The high resin-extractable  $P_2O_5$  observed in sole maize at  $150 \text{ kg ha}^{-1}$  of compound D and  $150 \text{ kg ha}^{-1}$  of AN treatment combination might be attributed to high phosphorus composition in the compound fertiliser.

Cropping system and fertiliser regime interaction had no significant effect on potassium, calcium and magnesium cations. However, it is worthy to note that all experimental plots had adequate calcium and magnesium contents with the acutely deficient potassium content. The high K-to-Mg ratio (average 1:50) implies that the relatively high Mg concentration in the soil can suppress K uptake by both the maize and legume crops thereby worsening the effects of low K concentration in the soils on crop productivity (Laekemariam et al. 2018). Therefore, there is a need to consider K fertilisation strategies that are in synchrony with K soil nutrient status in order to realize the expected potential of using legumes as live mulch in maize production in these soils.

With no fertiliser application and at an application rate of  $100 \text{ kg ha}^{-1}$  SSP, the sole maize and the maize-silverleaf intercrop failed to suppress weed emergence and growth. In contrast, the other cropping systems (the maize-velvet bean and maize-cowpea intercrops) were able to grow and produce a canopy that suppressed weed emergence and growth when no fertiliser was applied. Despite its potential to add N to the soil by the maize-velvet bean intercrops, velvet bean proved to be highly competitive against maize in this study. Silverleaf was the most compatible legume for intercropping with maize because of its capacity to produce a higher

maize grain yield than the other legumes. The  $150 \text{ kg ha}^{-1}$  compound D +  $150 \text{ kg ha}^{-1}$  AN fertiliser regime was the most efficient fertiliser that supplied maize with sufficient essential nutrients for plant growth. The maize-silverleaf cropping system has a higher potential to increase mineral nitrogen and resin-extractable  $P_2O_5$  than other cropping systems. Based on the results of this study, it is concluded that the best intercrop and fertiliser regime for stimulating N mineralisation and enhancing P availability is the maize-silverleaf cropping system at  $100 \text{ kg ha}^{-1}$  SSP. Further studies should be focused on the impact of these cropping systems under differential soil and agro-climatic conditions.

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### Disclosure statement

No potential conflict of interest was reported by the author(s).

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