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Sunflower Growth and Grain Yield under Different Tillage Systems and Sources of Organic Manure on Contrasting Soil Types in Limpopo Province of South Africa

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Abstract: A field study was conducted to assess the effect of tillage systems (TSs) and manure rates (MRs) on sunflower growth and yield at the University of Limpopo Experimental Farm (Syferkuil) which is on sandy loam soils and University of Venda Experimental Farm (UNIVEN) clayey soils, both located in Limpopo Province of South Africa for 2021/2022 and 2022/2023 cropping seasons. The experimental design was a split plot with three replications. The main plot was the tillage treatments: conventional (CON) and in-field rainwater harvesting (IRWH), while the subplots were the manure treatments: viz. poultry and cattle manures at rates of 20 and 35 t ha^{-10}, plus a control (no manure application). The IRWH is a tillage technique that collects rainwater on a 2 m wide runoff strip into the 1 m wide basin where it infiltrates deep into the soil beyond the evaporation zone but is available for crop use. The results revealed that at Syferkuil IRWH had a significant increase ($p < 0.05$) on grain yield, head diameter, head dry matter and aboveground dry matter yield in both cropping seasons, whereas at UNIVEN, the significant increase was obtained on grain yield, head diameter, aboveground dry matter, plant height and stem girth during both cropping seasons. The effect of manure rate significantly increased with the application rate, with poultry manure at the highest rate of 35 t ha^{-1} significantly recording high mean values of grain yield, head diameter, head dry matter, aboveground dry matter, plant height and stem girth at both sites during the two cropping seasons. The increase in leaf area index and 100 seed weight by IRWH and manure rate application varied across the growing stages and cropping seasons with no consistent trend. At Syferkuil, TS and MR interaction was significant on head diameter and on aboveground dry matter at flowering stage in the first cropping season, whereas at UNIVEN, it was significant on head diameter in the first cropping season. Therefore, these results suggest that IRWH combined with poultry manure (35 t ha^{-1}) can be adopted to improve sunflower crop yield under similar management and environmental conditions. In the absence of poultry manure, farmers may opt to use cattle manure at a rate of 35 t ha^{-1} for better improved yield.

Keywords: *Helianthus annuus* L; IRWH; poultry manure; aboveground dry matter; conventional tillage

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1. Introduction

Sunflower (*Helianthus annuus* L.) is the third largest grain crop produced in South Africa after maize (*Zea mays* L.) and wheat (*Triticum aestivum*) [1,2]. Free State and North West provinces are the leading producers of this crop contributing 90.3% of total crop with Limpopo Province coming third [3]. Sunflower's ability to produce relatively consistent yields under adverse weather conditions and its overall characteristics of drought tolerance makes it an attractive crop for farmers in dryland production regions such as Limpopo Province [1]. Furthermore, it is well adjusted to a wide variety of soils from heavy to sandy loam soils. Another important characteristic is that it has a shorter growing season than maize so it can be planted a little later where conditions make it necessary, and it has also been found to withstand early frosts [4].

Sunflower seed is the most important source of oil for human consumption in South Africa as compared to other oil seed crops. Sunflower seed processed into oil and oilcake is generally higher than the quantities utilized for seed, animal feed manufacturing and other uses. Sunflower oil is a healthy and highly valued vegetable oil used by households, food industries, restaurants and feed industries [5]. The crop accounts for approximately 87% of vegetable oil output, making it a preferred crop over other oilseeds. Furthermore, sunflower seeds constitute 5% of the total cereal grain production in South Africa [3].

The gross value of sunflower seed produced in South Africa has been relatively unstable annually. In 2020, sunflower seed production contributed approximately 5.3% of gross value production for field crops, 21.13% lower as compared to the previous year in 2019 [5]. The rising demand for healthy vegetable oil and oilcake presents South African farmers, particularly smallholder farmers, with many opportunities in the sunflower sectors to boost their livelihoods and ensure food security. Despite a vast potential for sunflower to contribute towards satisfying the future oil demand, the smallholder farming sector is still faced with the task of improving yield whilst making sure the oil content is not compromised [1].

However, since 2011, the production of sunflower seed in South Africa has been volatile in almost all the major producing provinces which resulted in some great variations in yield [1,5]. In 2020, the national yield average increased by almost 20% to 1.58 t ha^{-1}, which is the highest national average yield reported since the early 1980s but lower than the world's yield average of 2.04 t ha^{-1} [3]. In Limpopo Province, production has also been relatively low, hovering around 0.98 t ha^{-1} under dryland production [3]. The smallholder farmers contribute less to this yield, due to lack of capital, improved technologies and market access, exacerbated by small piece of lands they own [6,7]. Low soil fertility and low and unreliable rainfall are some of the cited constraining factors that influence the low production of sunflower crop among smallholder farmers in the province [7]. It is therefore essential that sunflower production in smallholder farming systems be improved to meet the oil demand of the increasing human population and recover economic development of the country, through exports and trade [1].

The in-field rainwater harvesting technique (IRWH) (Figure 1), introduced by Hensley et al. [8], promotes runoff on a 2 m wide no-till strip between alternate crop rows where rainwater is collected in basins and infiltrates into the soil profile beyond the surface evaporation zone, resulting in increased plant available water. The technique has been reported to increase sunflower and maize grain yield by more than 50% as compared to conventional tillage on different soil types [8–13]. However, most smallholder farmers in arid and semi-arid areas of Limpopo Province have a wide range of arable lands characterized by low soil fertility and low plant available water [14,15]. Therefore, the use of the IRWH technique alone in the province may not eradicate the problem of low sunflower yields. Previous studies have shown that smallholder farmers of Limpopo Province are experiencing soil nutrient depletion and frequent dry spells that significantly affect their crop production [7,16,17]. As pointed out by Mupangwa et al. [18], low crop yield under soil water management systems is sometimes compounded by poor soil fertility. The integration of rainwater harvesting technologies and application of organic sources of nutrients are promising climate-smart agricultural practices that could be widely used by smallholder farmers to maintain food security and secure farmers' livelihoods [19]. Therefore, the use of soil and water conservation technologies such IRWH for improved water productivity and organic manure to improve soil nutrient status in the semi-arid environments of diverse soil types is an important synergistic approach to improve smallholder farmer's rainfed crop production. The long dry spells and low erratic rainfall makes it hard for resource-poor farmers to produce the desired yield; therefore, the use of alternative rainwater harvesting techniques and organic amendments to improve water productivity and soil fertility will be a worthwhile option to explore. Therefore, this study aimed to evaluate the effect of the

IRWH technique integrated with organic manure application on sunflower growth and yield components.

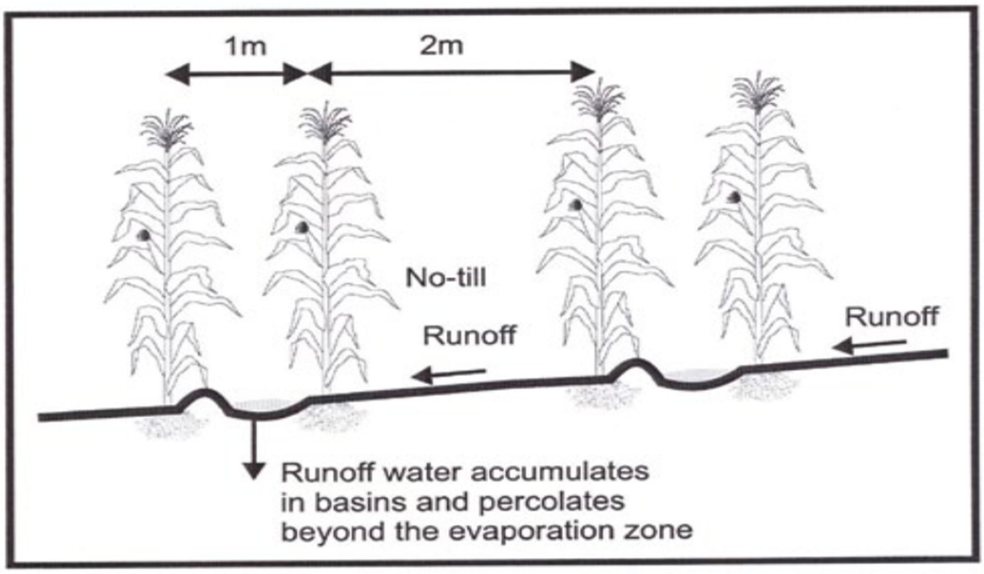

Figure 1. Schematic diagram of the in-field rainwater harvesting technique (after Hensley et al. [8]).

2. Materials and Methods

2.1. Study Sites Description

The study was carried out on two sites of Limpopo Province for two consecutive cropping seasons. The two sites were the University of Limpopo Experimental farm (Syferkuil) and the University of Venda Experimental Farm (UNIVEN). The two sites were chosen because they represent dominant soil types in the province [14]. Syferkuil (23°50′ S; 29°41′ E, 1324 m above sea level) is situated in the Mankweng area within the Polokwane local municipality of Capricorn District. The experimental site falls under a semi-arid region with an average annual rainfall of 500 mm occurring mostly in the summer months between October and March. The mean annual temperatures of 25 °C (max) and 10 °C (min) are common around the experimental site. The soils of the study area are dominantly derived from granite rock parent material. The soil is classified as the Bainsvlei soil form of the Florida family according to the South African soil classification system [20] equivalent to Chromic Stagnic Plinthic Cambisol/Regosol [21,22]. The soils are identified as sandy loam textures with an effective depth of 900 mm.

The University of Venda Experimental Farm (22°58′ S; 30°26′ E, 596 m above sea level) is located within the University of Venda premises. The university is located at Thohoyandou town which falls under the Thulamela Local Municipality of Vhembe District. The study site falls within the eastern part of the lowveld, which forms part of the greater Limpopo River basin. The study site receives about 800 mm of annual rainfall which varies temporally and is highly seasonal with 85% occurring between October and March (summer). Daily temperatures vary from about 25 °C to 40 °C in the summer and between 22 °C and 26°C in the winter. The soil is mainly derived from basalt rock of the Sibasa formation. The soil is classified as the Shortlands soil form of the Tongaat family [20] equivalent to Eutric Luvic/Alic Nitisol [21,22]. The soil is deep (>1200 mm) and dominated by clay (average 60%) textures and well drained [23,24].

2.2. Field Layout

A split plot design experiment was conducted with three replications, which consisted of two main plots (i.e., tillage system, 45 m × 4.5 m) and three subplots (manure application, 9 m × 4.5 m) treatments. The main plot treatments included IRWH with the ratio of 1:2 (cropping area: runoff area) and conventional tillage (CON). Subplot treatments included a control (no manure application), 20 and 35 t ha^{-1} of poultry manure (PM) and 20 and 35 t ha^{-1} of cattle manure (CM) [25,26]. The experimental plots were 1 m apart, giving an experimental site a total area of 1568 m^2. The manure treatments were randomized within each main (tillage) plot.

2.3. Tillage System

The conventional tillage (CON) involved the use of mouldboard plough followed by disc plough to prepare the soil for planting, mimicking the practice of the majority of smallholder farmers in the province. The IRWH technique (Figure 1) was prepared using spades, rakes and hoes to form basins and a runoff area following the mouldboard plough and disk plough. The slope of the runoff area was directed towards the basins to convey rainwater into the basins. The IRWH treatments had 2 m wide runoff strips that promoted rainfall runoff between alternating crops and stored the rainwater in the 1 m wide basins. The capacity of the basins was kept sufficient to ensure that it could hold the water runoff from the largest rainstorm. Sunflower seeds were planted in the tramline row spacing (2 m × 1 m) along the basins.

2.4. Manure Source, Analysis and Application

The organic manures comprised of the cattle manure (CM) and poultry manure (PM) were collected from local smallholder farmers. These two manure types are commonly used as soil amendments in smallholder farms of South Africa [27–29]. Before manure application, the two manures were sampled and analyzed for total C (%), total N (%), C/N ratio, pH, P and exchangeable cations (Ca, Mg, K and Na) using standard methods. Each manure was applied at a rate of 20 and 35 t ha^{-1} [30–33]. During application, the organic manures were crushed into smaller particles to increase the surface area for nutrient release and uniform distribution and incorporation in the field. The manures were applied to the soil at least 21 days before planting [34,35], to allow sufficient time to react with the soil, since the nutrients that are present in manure are not all immediately available to plants [36]. The manures were applied and incorporated in the soil using a hand hoe and rake to an approximate depth of 10 cm. For thorough incorporation of the manure in the soil, the selected manure sources were applied to their respective plots during land preparation (i.e., construction of the tillage systems in the first cropping season and maintenance of the tillage systems in the second cropping season). On the CON treatment, manures were applied evenly and incorporated at a depth of about 10 cm using a hand hoe and were covered with a rake. For IRWH, the manures were applied and incorporated carefully in the basins in order to maintain the good structure of the tillage system. No manures were applied on a 2 m wide runoff area of IRWH system.

2.5. Agronomic Data Collection

2.5.1. Plant Density and Spacing

Local sunflower landrace seeds were planted in tramline row spacing (2 m × 1 m) with 30 cm intra row spacing, which resulted in a plant density of 27,654 plant ha^{-1} which falls under the range of sunflower dryland production as recommended by Nel et al. [37]. Planting was carried out manually, placing two seeds per hole. At Syferkuil, the cropping periods were from the 15 January to 4 May 2022 and from 28 January to 10 May 2023 for the first and second cropping seasons, respectively. At UNIVEN, the periods were from 04 February to 13 May 2022 and from 27 January to 16 May 2023 for the two consecutive cropping seasons. The planting dates were determined by the onset of rainfall in each season after about 21 days of manure application Thinning was conducted after two weeks of emergence. Weeds were carefully removed manually in order to minimize soil disturbance, especially for IRWH systems. Pests and diseases were only controlled once in a cropping season using Malathion 50% EC.

2.5.2. Grain Yield

The two most inner middle rows were used for yield determination at harvest. The sunflower head diameter (cm), head dry matter (g head^{-1}) and 100 seeds weight were then measured. Grain yield was determined after threshing and being dried at 65 °C in the oven for more than 24 h. The seed weight was then adjusted to 13% moisture content and converted to kg ha^{-1}.

2.5.3. Leaf Area Index and Aboveground Dry Matter

Four plant samples were collected at three growing stages (i.e., flower bud, flowering and physiological maturity stage) for the determination of leaf area index (LAI). Plant samples were collected from the two outer rows to avoid central rows which were for grain yield determination at physiological maturity. Leaves were detached from the plant and used to measure leaf area using a calibrated leaf area meter (LI-COR model 3100). Leaf area was then divided by total sampled area (basin area) to compute LAI. Due to the absence of leaf area meter at Syferkuil, the sunflower leaf area was determined manually by measuring the width of a leaf using a measuring tape. Leaf area was then estimated using a linear Equation (1) adopted from Rouphael et al. [38]:

$$LA = 6.79 + 0.65W^2 \tag{1}$$

where W is the width of sunflower leaf in cm.

For the determination of aboveground dry matter, the same plant samples which were used for leaf area were used. Samples were then dried at 65 °C in an oven for 72 h for flower bud stage measurements and till constant weight for flowering and maturity stages and converted to a unit of kg ha^{-1}.

Plant height and stem girth were determined as follows: Two marked plants from each of the two inner rows were used to measure plant height and stem girth at three growing stages. A total number of four plants per plot were used and an average was obtained. The plant height was measured from the base (soil surface) of the plant to the tip of the top most leaf/head using a measuring tape. Height was measured in cm and finally the average plant height per plant was determined. Stem girth was measured in the middle of the stem.

2.6. Statistical Analysis

ANOVA was performed using IBM SPSS statistics version 20 software [39]. Treatment means were separated using least significant difference (LSD) at $p < 0.05$.

3. Results

3.1. Pre-Cropping Selected Soil Properties of the Experimental Sites

The selected pre-cropping soil properties for both sites are depicted in Table 1. At Syferkuil, the soil was sandy loam with an average sand fraction of 67.5%. The soil had a constant bulk density (1.35 g cm^{-3}) at 0–20 and 20–40 cm depths. Aggregate stability was low and decreased with depth [40]. The pH of the soil was generally slightly alkaline. The soil had low OC and high total N, both decreasing with depth. The available phosphorus content ranged from high (14.93 mg kg^{-1}) to medium (8.04 mg kg^{-1}) [41]. The exchangeable cations (Ca, Mg, K and Na) were found to be adequate. At the UNIVEN site, the soil was dominated by clay fraction (>58%) with low bulk density and high aggregate stability [40]. The soil was acidic in reaction with a pH ranging from 5.90 to 5.52. The OC and total N were generally higher [41], both decreasing with depth. The phosphorus content was low. The exchangeable cations were moderately decreasing with depth.

Table 1. Pre-cropping selected soil properties.

Soil Properties	Depth (cm)	Syferkuil	UNIVEN
		Soil physical properties	
Sand (%)	0–20	67	23
	20–40	68	24
Silt (%)	0–20	18	17
	20–40	15	18
Clay (%)	0–20	15	60
	20–40	17	58
Bulk density (g/cm^3)	0–20	1.35	1.17
	20–40	1.35	1.22
Aggregate stability (g/g)	0–20	0.2911	0.6241
	20–40	0.2108	0.4629
		Soil chemical properties	
pH (H_2O)	0–20	7.30	5.90
	20–40	7.34	5.52
Organic carbon (%)	0–20	0.74	1.70
	20–40	0.66	1.12
Total N (%)	0–20	0.070	0.067
	20–40	0.061	0.042
Available P (mg/kg)	0–20	14.93	4.77
	20–40	8.04	1.86
Ca (mg/kg)	0–20	890	980
	20–40	902	884
Mg (mg/kg)	0–20	441.6	247.2
	20–40	469.2	229.2
K (mg/kg)	0–20	226.2	113.1
	20–40	218.4	93.6
Na (mg/kg)	0–20	36.8	23.0
	20–40	39.1	20.7

3.2. Chemical Properties of the Organic Manure

Table 2 shows the analytical results of the two organic manures used. Both organic manures were alkaline in reaction with cattle manure (CM) recording higher pH values than poultry (PM). The two organic manures had a similar content of total carbon and total N with PM recording slightly higher values for these properties. The available P of PM was found to be three times higher than CM. The PM further recorded higher values of exchangeable basic cations except for Mg. Due to their similar content of total C and total N, the two organic manures had similar C:N ratios with CM recording slightly higher values.

Table 2. Chemical properties of organic manures used in the experiment.

Organic Manure Sources	pH (H_2O)	Total C (%)	Total N (%)	P (g kg^{-1})	K (g kg^{-1})	Na (g kg^{-1})	Ca (g kg^{-1})	Mg (g kg^{-1})	C/N Ratio
CM	8.54	28.3	2.10	4.27	14.6	2.53	18.80	13.30	13.5:1
PM	7.42	30.4	2.31	12.28	17.8	3.89	35.90	10.2	13.2:1

3.3. Meteorological Conditions at the Experimental Sites

The rainfall amounts varied between the seasons at both sites with higher amounts received in the second cropping season (Table 3). Even though UNIVEN recorded high rainfall amounts in both cropping seasons as compared to Syferkuil, both sites experienced dry spells towards the end of each cropping season (Table 3). At Syferkuil, the rainfall amount in the second cropping season was two-fold higher than the first cropping season. The first cropping season at Syferkuil had a monthly even rainfall distribution as compared to the second cropping season, where in the second cropping season, about 176 mm of rainfall was received in a single month of February which is more than 935% higher compared to the second higher rainfall amount (17.2 mm) received in March (Table 3). At UNIVEN, the monthly rainfall distribution was poor in the second cropping season as compared to the first, where the months of April and May received amounts of 19.6 mm and 0.51 mm in one day, respectively. In addition, the month of February in the second cropping season received about 435 mm of rainfall which is 20% higher than the rainfall received in the entire first cropping season (Table 3).

Table 3. Monthly rainfall data during 2021/2022 and 2022/2023 cropping seasons at Syferkuil and UNIVEN.

	Syferkuil				**UNIVEN**			
				2021/2022 cropping season				
Date	Rainfall (mm)	Rainy days [c]	Temperature (max)	Temperature (min)	Rainfall (mm)	Rainy days [c]	Temperature (max)	Temperature (min)
22 January	53.08 [a]	5	27.33	15.64				
22-February	49.02	8	30.18	15.13	17.77 [a]	7	31.18	32.30
22-March	8.86	8	27.21	13.87	102.6	11	29.51	30.03
22-April	3.8	4	25.45	11.94	241.03	13	26.78	27.53
22-May	0.0 [b]	0	25.14	6.02	0.0 [b]	0	26.94	27.97
Total/average	114.76	25	27.06	12.52	361.40	31	28.60	29.46
				2022/2023 cropping season				
23 January	10.67 [a]	2	29.52	16.73	7.36 [a]	2	33.24	19.37
23 February	175.95	14	27.07	17.10	434.9	21	29.88	20.43
23 March	17.02	5	28.04	13.58	31.24	9	30.09	18.14
23 April	1.27	2	29.89	14.30	19.6	1	30.8	15.24
23 May	9.90 [b]	4	26.00	10.16	0.51 [b]	1	28.76	14.82
Total/average	214.81	27	28.10	14.37	493.61	34	30.55	17.60

[a] rainfall received on or after planting; [b] rainfall received on or before harvest; [c] number of rainfall days in a month.

The temperature values in both cropping seasons were generally similar for each site. UNIVEN recorded high temperatures in both seasons compared to Syferkuil. Syferkuil recorded higher mean temperatures in the second cropping season compared to the first cropping season. In contrast to other mean temperature trends, the mean minimum temperature at UNIVEN was higher than the mean maximum temperature in the first cropping season. This has resulted in both mean maximum and minimum temperatures not having the same trend when comparing the two cropping seasons, with mean maximum temperatures having higher values in the second cropping season, whereas the mean minimum temperature had high values in the first cropping season (Table 3).

3.4. Analysis of Variance (ANOVA) on the Effect of Cropping Season, Tillage System, Manure Rate and Their Interactions on Sunflower Grain Yield and Yield Components at Syferkuil

Grain yield (kg ha^{-1}) was significantly influenced ($p < 0.05$) by cropping season, tillage system and manure rate but their interactions had no effect (Table S1). Cropping season significantly ($p < 0.05$) influenced all the sunflower yield parameters except for 100 seed weight (g), plant height at flower bud stage and stem girth at flower bud and maturity stages. Tillage system had a significant effect on all sunflower parameters except for 100 seed weight, leaf area index (LAI) at maturity stage, plant height at flower bud stage and stem girth. Leaf area index (LAI) at maturity stage was only influenced by the cropping season. Manure rate significantly affected all sunflower yield parameters except for 100 seed weight and LAI at maturity stage. The interaction between tillage system and manure rate had a significant effect on head diameter only, whereas the interaction among cropping season, tillage system and manure rate had a significant effect on aboveground dry matter at flower bud stage (Table S1).

3.5. ANOVA on the Effect of Cropping Season, Tillage System, Manure Rate and Their Interactions on Sunflower Grain Yield and Yield Components at UNIVEN

Cropping season had a significant effect on all sunflower yield and yield components except for 100 seed weight, aboveground dry matter (kg ha$^{-1)}$ and LAI both at flower bud stage as well as stem girth at maturity stage. The tillage system did not affect head dry matter and 100 seed weight whereas manure rate did not affect 100 seed weight only. Interaction between cropping season and tillage system had a significant effect on head dry matter, LAI at flowering and maturity stages and stem girth at flowering stage (Table S2). The interaction between cropping season and manure rate significantly affected LAI and stem girth at flowering and maturity stage. The tillage system and manure rate had a significant effect on head diameter and plant height at flower bud stage (Table S2).

3.6. Effect of Tillage System on Grain Yield, Head Diameter, Head Dry Matter and 100 Seed Weight

Tillage system (TS) had a significant effect ($p < 0.05$) on grain yield, head diameter and head dry matter for both cropping seasons at both sites (Tables 4 and 5). At both sites, IRWH recorded the highest mean values of grain yield and head diameter in both cropping seasons compared to CON treatment. At Syferkuil, IRWH recorded an almost two-fold and 40% higher grain yield than CON in the first and second cropping seasons, respectively, whereas at UNIVEN, IRWH recorded more than a third (34%) ($p < 0.05$) increase in each season (Tables 4 and 5). IRWH significantly increased head diameter by 23% and 7% during the first and second cropping season at Syferkuil site. At UNIVEN, the head diameter was significantly increased by IRWH by about 8% in both seasons. The effect of tillage system on head dry matter varied across cropping seasons and experimental sites with no consistent trend. At Syferkuil, IRWH increased the head dry matter by 55% and 15% in the first and second cropping seasons, respectively. In contrast, at UNIVEN, CON showed a significant increase (9%) in head dry matter in the first cropping season over IRWH, whereas in the second cropping season, the significant increase was observed under IRWH over CON. The tillage system recorded high mean values for grain yield and head diameter in the second cropping season as compared to the first cropping season at both sites. The tillage system showed no significant effect on the 100 seed weight at both sites. Even though not significantly affected by TS, IRWH showed a slight increase for 100 seed weight for both cropping seasons at Syferkuil, whereas at UNIVEN, the increase was only observed in the first cropping season.

3.7. Effect of Manure Rate on Grain Yield, Head Diameter, Head Dry Matter and 100 Seed Weight

Manure rate (MR) had a significant effect ($p < 0.05$) on grain yield in the second cropping season at Syferkuil, whereas at UNIVEN, the significant difference was observed under both seasons. Head diameter and head dry matter were significantly influenced by MR in both cropping seasons at both sites. The MR significantly increased with the application rate, with poultry manure at a rate of 35 t ha^{-1} (35PM) recording significantly higher mean values of grain yield in both seasons at Syferkuil followed by 35CM, 20PM, 20CM and 0, in that order (Tables 4 and 5). At UNIVEN, the same trend was observed in the first cropping season only with the second cropping season increasing in the following pattern: 35PM, 20PM, 35CM, 20CM and 0. Even though 35CM showed to be superior on grain yield, the manure application rate did not show to be significantly different among themselves, except for 0, particularly at UNIVEN. Manure rate significantly increased the head diameter and head dry matter in the order of 35PM, 35CM, 20CM, 20PM and 0, in both cropping seasons at UNIVEN, whereas at Syferkuil, the trends of the two parameters varied between the cropping seasons but with 35PM recording great values throughout (Tables 4 and 5). MR had no significant effect on 100 seed weight but the high mean values were recorded in the second cropping seasons for both sites. The increasing trend of 100 seed weight between the cropping seasons of both sites was not consistent.

Table 4. Means for sunflower grain yield (GY), head diameter (HD), head dry matter (HDM) as influenced by tillage system and manure rate at Syferkuil.

Treatment	GY (kg ha^{-1})	HD (cm)	HDM (g Plant^{-1})	100 Seed Weight (g)
Tillage System (TS)	2021/2022 cropping season			
CON	1746.51 a	17.47 a	50.01 a	5.91 a
IRWH	3390.97 b	21.43 b	77.43 b	6.01 a
Manure rate (MR)				
0	1943.87 a	15.17 a	33.53 a	5.74 a
20PM	2514.76 ab	20.64 b	66.31 b	5.90 a
35PM	3261.64 b	22.56 c	89.50 c	6.15 a
20CM	2236.10 a	17.78 d	57.04 d	5.92 a
35CM	2887.32 b	21.11 b	72.21 b	6.07 a
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns
MR	ns	$p < 0.05$	$p < 0.05$	ns
TS × MR	ns	$p < 0.05$	ns	ns
Tillage system (TS)	2022/2023 cropping season			
CON	2731.67 a	26.21 a	32.80 a	5.98
IRWH	3816.75 b	28.12 b	37.72 b	6.15
Manure rate (MR)				
0	1941.75 a	21.39 a	28.95 a	6.01
20PM	3213.15 ab	29.78 bc	37.91 bc	6.14
35PM	4945.60 c	31.03 b	39.42 c	6.03
20CM	2447.21 ab	26.06 d	34.43 d	6.03
35CM	3823.35 bc	27.58 dc	35.59 bd	6.12
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns
TS ×MR	ns	ns	ns	ns

Means in the same column followed by the same letter are not significantly different; ns = not significant at 5% probability level.

Table 5. Means for sunflower grain yield (GY), head diameter (HD) and head dry matter (HDM) as influenced by tillage system and manure rate at UNIVEN.

Treatment	GY (kg ha^{-1})	HD (cm)	HDM (g Plant^{-1})	100 Seed Weight (g)
Tillage system (TS)	2021/2022 cropping season			
CON	1357.54 a	19.15 a	44.17 a	6.00 a
IRWH	1821.99 b	20.75 b	40.67 b	6.024 a
Manure rate (MR)				
0	1108.70 a	16.22 a	27.90 a	5.88 a
20PM	1685.48 b	19.58 b	36.36 ab	6.07 a
35PM	1850.48 b	22.09 c	56.27 c	6.14 a
20CM	1486.68 ab	20.00 b	41.55 db	5.99 a
35CM	1817.49 b	21.83 c	50.04 dc	5.99 a
TS	$p < 0.05$	$p < 0.05$	ns	ns
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns
TS × MR	ns	$p < 0.05$	ns	ns
Tillage System (TS)	2022/2023 cropping season			
CON	1715.45 a	19.67 a	32.60 a	6.08 a
IRWH	2302.54 b	21.38 b	37.84 b	6.05 a
Manure rate (MR) (t ha^{-1})				
0	1319.81 a	17.14 a	27.02 a	6.05 a
20PM	2237.38 b	19.97 b	32.84 b	6.05 a
35PM	2443.32 b	22.64 c	42.54 c	6.10 a
20CM	1823.94 ab	21.08 bd	34.84 bd	6.09 a
35CM	2220.53 b	21.78 cd	38.87 cd	6.04 a
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns
TS × MR	ns	ns	ns	ns

Means in the same column followed by the same letter are not significantly different; ns = not significant at 5% probability level.

3.8. Effect of Tillage System on Aboveground Dry Matter and Leaf Area Index (LAI) of Sunflower under Three Growing Stages

The tillage system significantly affected the aboveground dry matter under all growing stages for both cropping seasons at both sites. At Syferkuil, TS had a significant effect on leaf area index (LAI) in the flower bud and flowering stage of the first and second cropping seasons, respectively (Table 6). At UNIVEN, LAI was significantly affected by tillage system, except during the flowering stage of the second cropping season (Table 7). IRWH has reported a significant increase in aboveground dry matter and LAI under all growing stages and cropping seasons at both sites except for LAI in the maturity stage of both seasons at Syferkuil. The tillage system recorded high mean values for the aboveground dry matter and LAI in the second cropping season than the first cropping season except for the aboveground dry matter under flowering stages at UNIVEN and LAI under maturity stage at Syferkuil.

Table 6. Means for sunflower aboveground dry matter, leaf area index (LAI) plant height, stem girth, grain yield (GY), head diameter (HD) and head dry matter (HDM) as influenced by tillage system and manure rate at Syferkuil.

Treatment	Aboveground Dry Matter (kg ha^{-1})			LAI			Plant Height (cm)			Stem Girth (cm)		
	FBS	FS	MS	FBS	FS	MS	FBS	FS	MS	FBS	FS	MS
Tillage System (TS)	2021/2022 cropping season											
CON	936.10 a	3453.23 a	4948.37 a	0.799 a	0.953 a	1.269 a	82.12 a	129.57 a	135.17 a	7.20 a	10.83 a	10.69 a
IRWH	1298.57 b	3711.20 b	5574.10 b	0.834 b	0.964 a	1.078 a	91.37 b	127.50 a	134.93 a	7.93 a	10.82 a	10.92 a
Manure rate (MR)												
0	756.00 b	3345.83 a	4884.33 a	0.754 a	0.916 a	1.053 a	65.33 a	103.33 a	110.58 a	5.75 a	8.58 a	8.63 a
20PM	1098.27 a	3583.50 b	5116.73 a	0.817 bc	0.974 a	1.075 a	88.88 bc	136.67 b	143.42 b	8.33 bc	11.50 bc	11.46 b
35PM	1406.40 c	3886.07 c	5752.33 b	0.857 b	0.976 a	1.102 a	100.38 c	146.42 b	153.08 b	9.42 b	12.54 b	11.92 b
20CM	989.10 a	3436.33 a	5104.90 a	0.811 c	0.969 a	1.069 a	84.75 b	122.17 ba	130.08 ba	6.83 a	9.96 ac	10.25 ab
35CM	1286.93 c	3659.40 b	5447.93 c	0.843 bc	0.960 a	1.068 a	94.38 bc	134.08 b	138.08 b	7.50 ac	11.54 b	11.75 b
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	ns	$p < 0.05$	ns	ns	ns	ns	ns
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	ns	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
TS × MR	ns	$p < 0.05$	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage System (TS)	2022/2023 cropping season											
CON	1208.77 a	4340.37 a	5274.23 a	0.835 a	0.972 a	1.096 a	86.233 a	174.767 a	194.883 a	8.017 a	9.517 a	11.083 a
IRWH	1444.17 b	5547.17 b	6896.67 b	0.851 a	1.042 b	1.094 a	86.700 a	202.717 b	215.117 b	8.250 a	10.283 a	11.800 b
Manure rate (MR)												
0	1206.00 a	3746.60 a	5354.67 a	0.830 a	0.877 a	1.092 a	60.88 a	164.58 a	188.71 a	6.13 a	8.04 a	9.58 a
20PM	1349.90 b	5037.00 b	6087.17 b	0.837 a	0.991 b	1.095 a	101.25 bc	187.75 b	204.21 b	9.38 bc	10.58 b	12.21 b
35PM	1423.33 c	5493.43 c	6560.6 c	0.850 a	1.082 c	1.089 a	119.08 c	205.54 c	220.71 c	10.54 c	11.96 c	13.21 c
20CM	1262.40 a	5047.43 b	6111.6 bc	0.834 a	0.987 b	1.097 a	76.25 ab	181.92 b	198.08 b	6.72 a	8.83 a	10.38 a
35CM	1390.67 bc	5394.40 bc	6313.23 bc	0.863 a	1.098 c	1.102 a	74.88 ab	203.92 c	213.29 c	7.92 ab	10.08 b	11.83 b
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	$p < 0.05$	ns	ns	$p < 0.05$	$p < 0.05$	ns	ns	$p < 0.05$
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	$p < 0.05$	ns	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
TS × MR	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Means in the same column followed by the same letter are not significantly different; ns = not significant at 5% probability level; FBS = flower bud stage; FS = flowering stage; MS = maturity stage.

3.9. Effect of Manure Rate on Aboveground Dry Matter and Leaf Area Index (LAI) of Sunflower under Three Growing Stages

The manure rate (MR) significantly affected the aboveground dry matter under all growing stages for both seasons at both sites. LAI at Syferkuil was significantly affected by MR under flower bud and flowering stages in the first and second cropping seasons, respectively. At UNIVEN, the significance effect on LAI was observed throughout the growing season in the first cropping season and under the flower bud and maturity stages in the second cropping season. Poultry manure at a rate of 35 t ha^{-1} was observed to significantly increase aboveground dry matter over other manure rates throughout the three growing stages for both seasons at both sites. At Syferkuil in the first cropping season, the aboveground dry matter was increased in the following order: 35PM, 35CM, 20PM, 20CM and control. A similar trend on aboveground dry matter was observed throughout the growing stages at UNIVEN during the second cropping season. Although without a consistent increasing trend, 35PM increased the LAI in the first cropping season over the other manure rates throughout the growing stages at both sites. Control treatment recorded the lowest means of aboveground dry matter at all growing stages during the two consecutive seasons at both sites, whereas the lowest LAI means at all growing stages were recorded in the first cropping season of the two sites.

Table 7. Means for sunflower aboveground dry matter, leaf area index (LAI) plant height, stem girth, grain yield (GY), head diameter (HD) and head dry matter (HDM) as influenced by tillage system and manure rate at UNIVEN.

Treatment	Aboveground Dry Matter (kg ha^{-1})			LAI			Plant Height (cm)			Stem Girth (cm)		
	FBS	FS	MS	FBS	FS	MS	FBS	FS	MS	FBS	FS	MS
Tillage system (TS)	2021/2022 cropping season											
CON	1077.23 a	4129.97 a	5295.43 a	0.882 a	1.820 a	2.243 a	76.93 a	187.00 a	189.63 a	7.40 a	9.61 a	9.97 a
IRWH	1206.77 b	5414.97 b	6826.90 b	0.981 b	2.357 b	3.040 b	89.27 b	198.63 b	203.50 b	8.48 b	11.17 b	11.42 b
Manure rate (MR)												
0	925.57 a	4077.23 a	5633.40 a	0.703 a	1.659 a	2.344 a	72.42 a	183.42 a	187.75 a	6.86 a	9.69 a	9.93 a
20PM	1118.93 bd	4372.33 ab	5995.00 ab	0.937 b	1.822 a	2.554 ab	80.33 b	187.75 a	192.75 a	7.68 b	9.95 a	10.07 a
35PM	1359.50 c	5662.73 c	6678.93 c	1.154 c	2.571 c	2.948 c	92.50 c	205.50 b	208.58 b	8.77 c	11.01 b	11.17 b
20CM	1076.40 d	4661.57 ab	5858.43 ab	0.890 b	2.120 b	2.576 ab	79.92 b	187.67 a	191.33 a	7.86 bd	10.52 c	10.82 ab
35CM	1229.57 bc	5088.50 bc	6140.10 b	0.973 b	2.271 b	2.787 bc	90.33 c	199.75 b	202.42 b	8.53 dc	10.78 bc	11.49 b
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
TS × MR	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tillage System (TS)	2022/2023 cropping season											
CON	1117.03 a	3975.53 a	6502.97 a	0.900 a	2.152 a	2.364 a	78.35 a	174.92 a	183.40 a	5.53 a	7.77 a	9.45 a
IRWH	1283.67 b	4771.50 b	7702.97 b	0.999 b	2.237 a	3.543 b	93.70 b	193.52 b	202.27 b	6.95 b	10.12 b	11.40 b
Manure rate (MR) (t ha^{-1})												
0	962.43 a	3652.23 a	6603.43 a	0.838 a	2.147 a	2.385 a	72.38 a	171.29 a	176.75 a	4.83 a	7.25 a	8.13 a
20PM	1161.33 b	4363.90 bd	7049.93 b	1.002 b	2.212 a	2.489 a	85.04 b	184.29 bd	192.63 b	6.17 b	8.67 b	9.96 b
35PM	1410.67 c	5087.10 c	7524.73 c	1.001 b	2.316 a	2.502 a	94.96 c	193.08 c	202.00 c	7.25 c	10.17 c	11.92 c
20CM	1109.10 b	4063.27 b	7039.07 b	0.944 b	2.193 a	2.378 a	86.17 b	182.58 b	194.25 b	6.17 b	8.88 b	10.88 bc
35CM	1358.23 c	4701.07 d	7297.67 bc	0.965 b	2.102 a	2.515 a	91.58 c	189.83 bd	198.54 bc	6.79 bc	9.75 c	11.25 c
TS	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
MR	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	ns	ns	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
TS × MR	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Means in the same column followed by the same letter are not significantly different; ns = not significant at 5% probability level; FBS = flower bud stage; FS = flowering stage; MS = maturity stage.

The MR significantly increased with the application rate, with poultry manure at 35 t ha^{-1} recording high mean values at both sites at all growing stages except for stem girth. At Syferkuil, MR increased the grain yield, head diameter and head dry matter in the following order: 35PM, 35CM, 20PM, 20CM and control in both seasons (Table 4). At UNIVEN, a similar trend was only observed on grain yield in the first cropping season. Head diameter and head dry matter at UNIVEN, were significantly increased by 35PM followed by 35CM, 20CM, 20PM and the control in that order, under both cropping seasons (Table 5).

Manure rate recorded higher grain yield and dry matter in the second cropping season than in the first cropping season at both sites, except for grain yield and dry matter during flowering stage under the control treatment at Syferkuil and UNIVEN, respectively.

3.10. Effect of Tillage System on Plant Height and Stem Girth of Sunflower under Three Growing Stages

The tillage system significantly influenced plant height and stem girth under all growing stage at UNIVEN (Table 7). At Syferkuil, TS significantly affected plant height in the flower bud stage, and flowering and maturity stages of the first and second cropping seasons, respectively, whereas stem girth was only influenced under maturity stage in the second cropping season (Table 6).

3.11. Effect of Manure Rate on Plant Height and Stem Girth of Sunflower under Three Growing Stages

The manure rate significantly (<0.05) affected plant height and stem girth under three growing stages of the two cropping seasons at both sites (Tables 6 and 7). Poultry manure at a rate of 35 t ha^{-1} was shown to significantly increase plant height and stem girth over other manure rates and type under all growing stages of both cropping seasons at both sites. Even though there was no continuous trend, cattle manure at a rate of 35 t ha^{-1} was shown to follow 35PM in most instances for both sites.

4. Discussion

4.1. Effect of Tillage System and Manure Rate on Grain Yield, Head Diameter, Head Dry Matter and 100 Seed Weight

The tillage system had a significant effect on grain yield and head diameter in both cropping seasons for both sites with IRWH recording higher means than CON (Tables 4 and 5). The higher sunflower grain yield and head diameter observed under IRWH compared to CON in both cropping seasons at both sites could be attributed to the ability of IRWH to capture and conserve more rainwater to improve the sunflower yield under different soil types of semi-arid regions [10,11]. The two-fold grain yield increase by IRWH in the first cropping season at Syferkuil may be attributed to the ability of IRWH to capture and store rainwater efficiently even under low rainfalls compared to CON [11,42]. The 34% increase in grain yield in both seasons by IRWH over CON at UNIVEN showed that IRWH consistently increased rainwater storage even under different rainfall amounts. Like these findings, Joseph [43] and Mzezewa et al. [11] recorded a 36% and 56% increase in maize and sunflower grain yield under IRWH compared to CON on sandy loam and clayey soils, respectively. In addition, in their studies, Tesfuhuney et al. [12] observed a higher maize grain yield under IRWH compared to CON at Morago and Paradys villages of Thaba Nchu in the Free State province of South Africa. These results are also in conformity with the findings of Naba et al. [44] who reported that the grain yield of maize was significantly increased ($p < 0.05$) in targa (equivalent to IRWH) (7.15 t ha^{-1}) followed by tie ridge (6.19 t ha^{-1}), zai pit (4.50 t ha^{-1}) and control (equivalent to CON) (4.90 t ha^{-1}) treatments on a sandy loam soil of Humbo Woreda, Ethiopia. Their results indicated a 46% increase in grain yield by targa over CON. The high mean values of grain yield and head diameter recorded by tillage system in the second cropping season over the first cropping season at both sites may be attributed to the high rainfall amounts received in the second season (Table 3) coupled with the longer implementation of IRWH technique that has formed a crust to enhance in-field runoff [11] and a longer fallow period that enables IRWH to store more rainwater compared to CON [45,46]. In contrast to grain yield and head diameter, tillage system recorded high mean values for head dry matter in the first cropping season than in the second cropping season. These findings may be attributed to the better rainfall distribution in the first cropping season as compared to the second cropping season (Table 3). Even though not significantly affected, the 100 seed weight recorded high mean values under IRWH than CON except at UNIVEN in the second cropping season.

Manure rate had a significant effect on grain yield, head diameter and head dry matter in both cropping seasons at UNIVEN, but at Syferkuil, the significant effect on grain yield was only observed in the second cropping season (Tables 4 and 5). The high means of grain yield, head diameter and head dry matter recorded by 35PM could be attributed to the high nutrient content of PM (Table 2), its ability to retain moisture and the high rate applied. In their studies, Azeez and van Averbeke [28] and Bakayoko et al. [47] reported that poultry manure had the greatest content of organic matter, total N, C, P, K and Ca and lowest C:N ratio ($p < 0.05$) over cattle manure.

The high grain yield and head diameter means recorded in the second cropping season of both sites over the first season could be attributed to the addition of organic manure in the second cropping season [31] and the amount of rainfall received in the second cropping season which is higher than the rainfall received in the first cropping season (Table 3). A significant increase in grain yield by poultry manure due to its high nutrient content has been reported by various researchers [33,48–50].

A study conducted for two consecutive seasons by Ahmad et al. [50] observed a significant increase in cotton yield under poultry manure (10 t ha^{-1}) as compared to cattle manure (20 t ha^{-1}), biochar (7 t ha^{-1}) and compost (10 t ha^{-1}) in both seasons. In contrast to grain yield and head diameter, manure rate recorded higher means of head dry matter in the first cropping season than the second cropping season. Nevertheless, poultry manure at a rate of 35 t ha^{-1} showed an increase in head dry matter in both cropping seasons. This significant increase in sunflower yield by manure rate is associated with the ability of organic manure to retain nutrients and moisture for a long period.

Vaidya et al. [51], in their study where water conservation techniques were integrated with organic manure, reported that poultry manure (0.75 t ha^{-1}) recorded high plant height, collar diameter and crown diameter of Simarouba glauca over CM (5 t ha^{-1}). In general, the yield increased significantly with increased manure rates, as observed in our study. This might be attributed to adequate balanced nutrients released by the soil due to favourable soil conditions that increased nutrient availability and soil moisture retention as previously reported [26,33,34].

The reason for the lower grain yield under the control in the second cropping season than the first cropping season at Syferkuil (Table 4) may be because of nutrient depletion from the first cropping season coupled with the leaching of most nutrients on highly leached sandy textured soils due to the higher rainfall received in the second cropping season than the first.

4.2. Effect of Tillage and Manure Rate on Aboveground Biomass, LAI, Plant Height and Stem Girth

IRWH recorded high means of aboveground dry matter and LAI over CON under all growing stages for both cropping seasons at both sites. IRWH further increased plant height and stem girth over CON throughout the growing stages during both cropping seasons at UNIVEN and only in the second cropping season at Syferkuil (Tables 6 and 7). This increasing trend by IRWH is mainly because of its ability to harvest and store more rainwater for crop use during cropping seasons and fallow periods. Like this finding, Tesfuhuney et al. [12] and Botha [10] observed higher aboveground dry matter under IRWH as compared to CON on different soil types. In contrast to these findings, Tesfuhuney et al. [52] reported a higher LAI of maize under CON treatment as compared to IRWH during 28, 38, 50, 63, 70 and 85 days after emergence at Morago Village of Thaba Nchu in the Free State province of South Africa.

During one cropping season field experiment, Tesfuhuney et al. [12] reported that higher plant heights of maize were observed under the IRWH compared to CON during the six growing stages (28, 38, 50, 63, 70 and 85 days after emergence) at both Morago and Paradys villages of Thaba Nchu in the Free State province of South Africa with soils of high clay content. These results agree with Ibraimo [53] who reported taller maize plant height under IRWH than CON and tied ridges throughout the growing seasons on sandy clay loam soils at Hatfield Experimental Farm in Pretoria (South Africa).

Contrary to our results, a study conducted under fine sandy soils by Chuene [42] reported significantly higher maize plant height and stem girth under CON treatment as compared to IRWH in all growing stages. The inconsistent results on plant height and stem girth at Syferkuil in the first cropping season may be attributed to the low and poor rainfall distribution coupled with the low clay content of the soils at the study site that has low water holding capacity. The lack of a consistent trend of plant height and stem girth during the growing stages was also observed by Chuene [42].

The observed low mean values of aboveground dry matter, plant height and stem girth during the flowering stage of the second cropping season as compared to the first cropping season at UNIVEN could be a result of moisture stress experienced during the 2023 April month where only 19.6 mm of rainfall was received in a single day compared to 241 mm of rainfall which was received in 13 days in the first cropping season (Table 3).

Kugedera et al. [54] and Kubiku et al. [55] reported that the effect of water stress in the semi-arid environments at critical growth stages such as flowering and grain filling is due to due to low and erratic rainfall which is unevenly distributed.

The decrease in sunflower yield because of moisture stress during flowering stage was also observed by Mzezewa et al. [11] on the same experimental site. Tesfuhuney [56] reported that the high water demand for crop productivity is during the flowering stage as water stress can drastically reduce yield. Even though the lower yield was observed under the flowering stage, IRWH reported a better yield than CON; again, this is simply because IRWH is known to store more water for longer periods while deep-rooted sunflower can utilize water from deeper soil layers even under soil moisture stress conditions, which is quite common in rainfed agriculture [57]. This can further be a result of organic manure that can retain more rainwater compared to bare soils [46]. Mansouri-Far et al. [58] indicated that when soil water content decreases, the plant yield per unit area declines.

The high means of aboveground dry matter, plant height and stem girth recorded by 35PM in all growing stages could be attributed to the high content of essential nutrients contained in the poultry manure that led to its direct role in crop nutrition (Table 2). These nutrients are slowly released and become available to the plant and promote plant growth yield after the decomposition of this manure over the cropping period. These findings also show that the variation in nutrient content of the organic manure sources will result in a significant variation in plant growth yield [47].

The significant increase in plant height, stem girth, grain yield and LAI of maize by poultry manure over sheep manure and horse manure was observed by Asfaw [59] at three, six, nine and twelve weeks after the planting of maize on a sandy loam-textured soil. A study by Sani et al. [60] reported a significant increase by poultry manure on amaranths plant height and LAI at 20 and 40 days after emergence as compared to cattle manure and control on sandy loam soil. Alamzeb et al. [61] reported that poultry manure significantly increased ($p < 0.05$) on wheat total dry matter at heading (561.5 g m^{-2}) and physiological maturity (1165.2 g m^{-2}) stages over cattle manure at heading (549.5 g m^{-2}) and physiological maturity (1152.9 g m^{-2}) stages. Usman [62] observed a significant increase by poultry manure (20 t ha^{-1}) on tomato plant height at 2, 4, 6 and 8 weeks after transplanting as compared to cattle and goat manure. Similar results were also reported by Mayele and Abu [63].

Even though the 35PM has been superior on most crop parameters during the growing stages, other treatments with organic manure application rates have been shown to have a significant increase in yield over control treatments. This may be due to the ability of organic manure to improve soil nutrient content, organic matter content, moisture retention capacity, infiltration, aggregate stability and bulk density [33,64].

The high sunflower yield means recorded in the second cropping season over the first season could be attributed to the cumulative effect of the addition of animal manure in the second cropping season [31] and the amount of rainfall received in the second cropping season which was higher than the rainfall received in the first cropping season (Table 3). These results are in agreement with many findings of several researchers who revealed that organic manure at various growing stages increases crop growth and yield [28,33,63]. Akparobi [31] recorded the highest plant height (123 cm) and dry matter (0.99 kg plant^{-1}) of amaranthus cruentus (red amaranth) under 35 t ha^{-1} of poultry manure as compared to 0, 15 and 25 t ha^{-1}.

5. Conclusions

Generally, tillage system and manure application had a significant effect on sunflower growth and grain yield on both experimental sites. IRWH resulted in higher grain yield, head diameter and head dry matter during both cropping seasons at the two experimental sites as compared to CON. The 100 seed weight was only increased by IRWH under both cropping seasons at Syferkuil. Throughout the growing stages in the two cropping seasons, IRWH increased the aboveground dry matter, LAI, plant height and stem girth at UNIVEN.

At Syferkuil, the consistent increase by IRWH under all growing stages was only observed on aboveground dry matter, plant height and stem girth in the second cropping season. Generally, the highest mean values were recorded in the second cropping season than the first, which implies that the longer the implementation of the IRWH, the higher the yield.

Manure application at different rates was shown to increase the growth and the yield of sunflower crop at both sites during the two seasons compared to the control. At both sites during the two cropping seasons, poultry manure at a rate of 35 t ha^{-1} was shown to significantly increase sunflower grain yield, head diameter and head dry matter followed by other manure application rates in no consistent order, with control treatment recording the lowest means. The results for the 100 seed weight were inconsistent and did not show a clear trend amongst the treatments. At both sites, aboveground dry matter, plant height and stem girth was shown to have been increased by poultry manure at a rate of 35 t ha^{-1} during all growing stages for two consecutive seasons followed by other manure rates in no consistent order but with the control recording the lowest means. LAI showed no consistent trend during the growing stages, but in most cases, it was increased by poultry manure at 35 t ha^{-1} at both sites. In most instances, 35CM was second best after 35PM with poultry manure and cattle manure both at 20 t ha^{-1} coming third and fourth, respectively.

The results of this study reveal that under a well-distributed average rainfall of these regions, implementation of IRWH with the application of organic manure will produce higher yields in the long run. Therefore, these results suggest that IRWH combined with poultry manure (35 t ha^{-1}) can be adopted to improve sunflower crop yield in areas with low unpredictable rainfall amounts and sandy loams to clayey textures. In the absence of poultry manure, farmers may opt to use cattle manure instead, for better improved yield.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14040857/s1, Table S1: ANOVA on the effect of cropping season, tillage system and manure rate on sunflower grain yield (GY), head diameter (HD), head dry matter (HDM), 100 seed weight, aboveground dry matter (ADM), leaf area index (LAI), plant height (PH) and stem girth (SG) at flower bud stage (FBS), flowering stage (FS) and maturity stage (MS) during 2021/2022 and 2022/2023 cropping season at Syferkuil.; Table S2. ANOVA on the effect of cropping season, tillage system and manure rate on sunflower grain yield (GY), head diameter (HD), head dry matter (HDM), 100 seed weight, aboveground dry matter (ADM), leaf area index (LAI), plant height (PH) and stem girth (SG) at flower bud stage (FBS), flowering stage (FS) and maturity stage (MS) during 2021/2022 and 2022/2023 cropping season at UNIVEN.

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