FINAL REPORT 2016/17

DETAILS

Project number		M106/11 (000350)
Project title		Evaluation of conservation agriculture principles on two soil types on the Highveld
Project manager		AA Nel
Co-worker(s)	Internal	W Deale, DM Mosiane, SB Mahlatsi, PR Mogotlwane, ZJ Xhasa, SC Swanepoel, JL Erasmus, OA Molale, MA Prinsloo
	External	ARC-ISCW: Collecting weather data. ARC-IAE: Collecting soil density data
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Final abstract

Conservation Agriculture (CA) consists of three principles, namely, minimum soil disturbance (no-till), multiple cropping, or crop rotation and maintenance of a soil cover. CA practiced as no-tillage is practiced on more than 120 million ha worldwide. The area in South Africa devoted to CA is still small due to, among others, uncertainty if it will succeed in the local environment and soils. The main benefits of CA is soil conservation, the recovery of soil quality and the sustainability that flows from it. Two field trials were established on a sandy Clovelly and a sandy loam Hutton soil in the northwestern Free State and North West provinces respectively with the aim to compare conventionally produced maize with maize produced in three conservation agriculture crop systems. Systems, consist of mono-cropped conventionally tilled (mouldboard ploughed on the sandy loam and deep ripped on the sandy soil) maize which served as control (CT) and three CA systems namely, no-till mono-cropped maize, no-till maize - legume rotation and no-till millet - maize - legume rotation. On the sandy loam soil, the legume was also substituted with sunflower as a second set of rotations. On the sandy loam soil of Buffelsvallei CA practices resulted in similar or increased yields due to CA. No-till resulted to an average improvement of 1407 kg ha^{-1} (34%). Rotation with cowpeas only, or, millet followed by cowpeas improved the yield of maize with a further 150 to 744 kg ha^{-1}. Improvements in yield and rainfall use efficiencies were present especially during seasons with drought when the CA yields were between 2641 and 4804 kg ha^{-1} higher than the yields of the CT system. Sunflower as the rotational crop in the CA systems did not result in a further improvement but reduced the effect of no-till. Indications are that improvements in yields and rainfall use efficiencies were due an improvement of the infiltration rate of rain water into the soil. No-till did not result in improved yields on the extreme sandy soil at Erfdeel. No-till yields were similar to CT yields only when maize was annually rotated with cowpeas. Some recommendations from these results are as follows: 1. The stark difference of the results between the two trial locations indicates that the extrapolation of results and propagation of CA principles across environments, should be done with caution. 2. Testing different no-till crop rotation systems, including aspects such as cover crops and the inclusion of animal production, for their profitability and production risk in the sandy loam and similar soils is needed. 3. As knowledge already exists that no-till usually succeeds on loamy and clayey soils, future CA research should concentrate on sandy and loamy sand soils (clay contents lower than 16%) as the effects of CA principles on the soil physical, chemical and other vital biological components are unclear and what the absolute minimum depth of soil disturbance in CA crop systems should be.

Keywords: Conservation agriculture, conventional tillage, maize, yield, sandy soil

INTRODUCTION

It is a known fact that regular and rigorous disturbance of a soil such as mouldboard ploughing results in declining its fertility, beneficial soil organisms and declining soil water-holding capacity. Physical, chemical and biological characteristics of soils constitute a complex combination that ultimately determines a soil's quality. Doran and Parkin (1994) defined soil quality as "the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality and promote plant and animal health".

Production systems are only sustainable when resource quality is maintained or improved. Conventional tillage, as it has been practised for probably more than 100 years on the Highveld, had a profound effect on the natural soil quality equilibrium, so much that all characteristics had been disrupted in one way or another. The decline in the soil carbon content, down to 30% of its original status, (du Toit *et al*., 1994) is one such disturbing consequence of conventional tillage.

Conservation Agriculture (CA), particularly no tillage is practised on more than 120 million ha worldwide, while the area in South Africa devoted to CA is minimal. The main benefit of CA is soil conservation and the sustainability that flows from it. A second benefit of CA is saving on fuel and machinery, an important aspect applicable to producers at all levels.

CA implies the adoption of three principles, namely, little or minimum disturbance of the soil (no-till if possible), multiple cropping practices (crop rotation) and permanent soil cover. CA advocates are of the opinion that the low adoption rate of CA might be due to a lack of awareness, resistance to change or lack of access to information among farmers. A number of studies have shown that some sandy soils on the Highveld are very susceptible to compaction and that maize yield increases with deep ripping or ploughing indicating that no-till might not succeed.

However, there are a number of unanswered questions e.g. when cover crops are a regular part of the cropping systems and sound crop rotation is introduced as defined in CA, will the need for regular, deep cultivation on the aeolian soils of the Highveld diminish? How effective will the most limiting resource, namely rainfall be utilised? What will the effect of CA be on weed-, insect-, nematode- and disease dynamics, soil fertility status, soil compaction and acidification, soil biological activity and ultimately, economic and production risks of maize production?

AIM

To compare conventionally mono-culture maize with maize grown in CA production systems over several seasons on two soils types in order to determine if CA will be successful, how it respond to climate variability, if the soil quality improves and find explanations for the responses.

MATERIALS AND METHODS

Two sites were identified during October 2008 for field trials. The first site was on a loamy sand soil on the farm Buffelsvallei (26.602 -26.495) in the Ventersdorp district. The second site, on a sandy soil was on the farm Erfdeel (27.027 -26.982) in the Viljoenskroon district. The soil form, family and textures of the two soil profiles are shown in Table 1. The soil nutrient contents of both trial sites since the onset of the field work in 2008 are shown in Table 2.

Table 1 Soil profile classification and texture to a depth of 60 cm at Buffelsvallei and Erfdeel

	Buffelsvallei	**Erfdeel**
Soil form	Hutton	Clovelly
Soil family	Stella	Twyfelaar
Slope (%)	1.2	0
Clay content (%)		
Depth: 0 - 5 cm	16	3
5 - 15 cm	16	3
15 - 30 cm	17	4
30 - 60 cm	22	5
Silt content (%)		
Depth: 0 - 5 cm	2	0
5 - 15 cm	2	0
15 - 30 cm	2	0
30 - 60 cm	3	0
Sand content (%)		
Depth: 0 - 5 cm	82	97
5 - 15 cm	82	97
15 - 30 cm	82	96
30 - 60 cm	75	95

Sand particle size distribution (%)	Very coarse	Coarse	Medium	Fine	Very fine	Very coarse	Coarse	Medium	Fine	Very fine
0 - 5 cm	3	25	26	38	5	0	1	51	45	3
5 - 15 cm	3	27	28	35	5	0	1	36	59	4
15 - 30 cm	2	25	27	38	6	0	1	42	55	2
30 - 60 cm	3	24	26	40	5	0	2	49	46	2

Table 2 Soil nutrient contents to a depth of 30 cm at Buffelsvallei and Erfdeel from 2008 to 2017

Sample date	pH (KCl)	P(Bray1) (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Na (mg/kg)	C (%)	Acid saturation (%)
Buffelsvallei								
Depth 0 - 5 cm								
Oct 2008	5.98	39.3	158.0	437	74.0	0.86	0.47	0.65
Aug 2009	6.02	40.8	194.0	409	72.0	4.42	0.45	0.32
Sept 2010	5.79	39.3	184.0	405	79.6	9.77	0.50	0.66
July 2011	5.49	55.5	250.0	338	76.1	11.40	0.61	0.57
July 2012	5.36	65.1	238.0	331	82.5	4.70	0.55	0.93
July 2013	5.40	44.5	191.0	342	87.2	1.63	0.47	0.76
July 2014	5.31	43.8	169.0	345	97.0	7.64	0.50	1.16
July 2015	5.66	45.4	232.9	333	112.9	1.19	0.60	0.58
July 2016	5.61	47.2	191.3	343	116.4	3.86	0.55	0.34
July 2017	5.44	50.8	212.9	340	109.2	3.67	0.62	0.61
Depth 5 - 15 cm								
Oct 2008	5.07	33.9	150.0	304	73.9	0.18	0.44	2.35
Aug 2009	4.61	30.1	120.0	257	71.3	3.81	0.40	3.16
Sept 2010	4.93	34.4	124.0	314	69.1	8.82	0.42	1.68
July 2011	4.47	41.7	117.0	258	54.5	9.54	0.51	5.65
July 2012	4.41	60.4	136.0	260	51.4	3.32	0.41	7.74
July 2013	4.92	34.5	153.0	301	58.7	7.18	0.31	2.32
July 2014	4.56	47.9	134.0	276	53.3	4.95	0.33	5.54
July 2015	4.65	52.6	153.6	242	59.1	1.14	0.35	4.96
July 2016	4.50	52.1	148.8	248	59.1	3.02	0.35	4.98
July 2017	4.46	42.1	131.6	262	56.2	2.33	0.42	6.52
Depth 15 - 30 cm								
Oct 2008	4.88	18.2	125.0	296	90.2	0.82	0.41	1.08
Aug 2009	4.77	9.9	116.0	317	99.1	3.75	0.38	1.15
Sept 2010	4.83	18.6	112.0	322	92.7	9.95	0.39	1.67
July 2011	4.63	16.8	95.6	287	82.5	8.83	0.94	2.09
July 2012	4.68	16.6	96.4	299	85.5	2.55	0.39	2.51
July 2013	4.58	17.3	104.0	282	71.9	4.70	0.29	3.67
July 2014	4.51	20.7	104.0	284	66.6	3.50	0.30	4.70
July 2015	4.56	19.3	112.1	267	67.9	0.81	0.31	3.91
July 2016	4.70	13.5	110.2	324	77.3	1.48	0.31	2.24
July 2017	4.90	6.9	92.6	363	96.2	2.54	0.38	1.10

				Erfdeel				
				Depth 0 - 5 cm				
Oct 2008	4.77	70.4	61.4	111.4	32.9	3.21	0.40	15.30
Aug 2009	5.06	71.2	59.0	133.3	30.7	5.06	0.38	6.07
Sept 2010*	5.09	77.1	27.5	149.8	37.2	8.29	0.32	5.91
July 2011	4.95	68.6	73.2	120.4	38.9	7.20	0.35	6.98
July 2012	5.32	81.7	97.0	160.0	39.3	1.50	0.34	3.84
July 2013	5.36	74.3	64.0	154.0	40.0	2.30	0.30	2.91
July 2014	6.08	71.5	79.0	257.0	39.4	3.30	0.31	1.51
July 2015	6.17	73.8	69.9	251.3	48.6	0.54	0.36	0.92
July 2016	6.11	70.3	69.0	257.5	53.5	2.07	0.37	0.56
				Depth 5 - 15 cm				
Oct 2008	4.60	82.7	41.3	115.8	31.9	3.29	0.39	22.70
Aug 2009	4.41	81.9	35.6	97.2	24.7	5.50	0.29	34.50
Sept 2010*	5.29	80.8	40.8	202.8	46.1	8.86	0.35	4.45
July 2011	5.17	72.0	61.8	158.5	36.9	8.50	0.37	6.62
July 2012	5.29	88.1	41.3	189.0	36.1	0.32	0.35	6.33
July 2013	5.14	82.6	47.0	154.0	34.1	1.57	0.24	8.89
July 2014	5.26	81.3	28.2	181.0	30.7	3.04	0.21	5.33
July 2015	5.28	86.3	45.9	162.7	30.9	0.43	0.24	4.00
July 2016	5.28	85.4	46.4	159.5	30.9	1.89	0.20	3.53
				Depth 15 - 30 cm				
Oct 2008	4.34	84.9	33.0	84.7	26.6	1.61	0.23	38.50
Aug 2009	4.18	67.4	32.6	78.1	24.5	5.08	0.25	50.10
Sept 2010*	4.97	77.9	45.3	184.0	43.0	7.89	0.30	6.43
July 2011	5.19	72.3	39.3	174.8	36.8	6.44	0.33	4.99
July 2012	5.03	85.2	36.5	161.5	30.9	0.43	0.29	8.62
July 2013	5.33	82.6	38.5	175.0	32.7	1.64	0.20	5.61
July 2014	4.87	77.7	29.3	141.0	30.2	2.57	0.16	10.00
July 2015	5.28	86.3	45.9	162.9	30.9	0.43	0.24	3.98
July 2016	4.86	74.1	42.4	139.8	26.5	1.75	0.15	7.53

* After liming and ploughing to correct acidity.

Plots consisted of 28 rows spaced 0.9 m wide and 20 m long at Buffelsvallei and 16 rows spaced 0.9 m wide and 30 m long at Erfdeel. A completely randomised block design with four replicates were used at both localities. Crop production systems consisted of one conventional tilled system as control and three CA systems with variation in their crop rotations:

1. Mono-cropped maize under conventional tillage as control system. Tillage consist of annual ripping 55 cm deep 0.9 m apart in August or September at Erfdeel and, chisel or mouldboard ploughing 25 - 30 cm deep at Buffelsvallei followed by disk harrowing 12 cm deep for seedbed

preparation (CT system).

2. No-till mono-cropped maize. The soil was disturbed to a depth of 10 cm on the plant row for seed and fertiliser placement only.
3. No-till maize - sunflower/legume rotation (legume only at Erfdeel).
4. No-till maize - millet - sunflower/legume rotation (legume only at Erfdeel).

Treatment 2, 3 and 4 represent crop systems with a step-wise addition of each principle of CA. Millet served as a cover crop and to adhere to the FAO guideline of three different crops for rotation. Legume (soyabean in 2008/09 and 2009/10, and cowpeas since 2010/11) and sunflower crops were arranged in split plots, that is 14 rows per plot assigned to each crop at Buffelsvallei. Each crop within a particular system were grown every season to be able to distinguish between seasonal and treatment effects.

Due to the results obtained from 2012/13 to 2015/16 at Erfdeel, the trial plan was altered in 2016/17 to determine the minimum required depth of soil disturbance to maximise the yield of maize in rotation with cowpea. Depths of disturbance by ripping consisted of 0, 20, 40 and 60 cm. The 2016/17 season served the purpose of establishing the cowpea rotational effect. The response of the 2016/17 maize to the depth of disturbance without a rotational effect is, however, reported in the results.

Daily weather variables were recorded for the duration of the trials by automatic stations at both localities. Rainfall, mean maximum temperatures and estimated potential evapotranspiration are shown in Table 3.

Soil strength was measured on three randomly selected points in maize plots at both trial localities during February or March of some selected seasons. A Geotron penetrometer was used with a conical probe with a diameter of 12 mm and the soil strength recorded to a depth of 600 mm.

The objective of the 2008/09 season was to establish the field trials and create a rotational effect, destroy any compaction by deep ripping of both trial areas for the last and create a mulch of crop residue on the CA allocated plots. The various annual agronomic inputs like cultivars used, fertilisation rate etc., were made according to recommendations for the localities. All inputs and actions taken at the two localities, are respectively shown in Tables 10 and 11 for Buffelsvallei and Erfdeel at the end of this report.

Table 3 Monthly accumulated rainfall, mean maximum temperatures and accumulated reference potential evapotranspiration at Buffelsvallei and Erfdeel

						Buffelsvallei							
Month	Jul	Aug	Sept	Oct	Nov	Des	Jan	Feb	Mar	Apr	May	Jun	Total/
						Rainfall (mm)							
2008/09								70	-	-	-	28	
2009/10	6	23	20	36	60	109	109	88	122	76	14	0	663
2010/11	0	0	0	10	73	126	98	77	90	81	11	34	600
2011/12	0	0	0	46	37	141	47	26	87	4	0	13	401
2012/13	0	0	25	39	46	164	101	32	88	45	1	0	541
2013/14	0	0	0	27	41	120	101	209*	103	4	2	3	609
2014/15	0	21	3	9	115	128	174	55	121	60	1	6	693
2015/16	4	0	73	4	49	31	88	48	50	54	55	1	457
2016/17	15	1	1	2	57	108	120	192	6	48	14	0	564
						Mean maximum temperature (C)							
2008/09								26.9	27.1	26.7	22.5	19.2	
2009/10	17.3	21.3	27.3	27.4	27.1	30.6	26.9	29.6	28.3	25.5	20.5	19.2	25.1
2010/11	13.8	23.7	28.5	29.8	28.8	28.6	27.2	28.2	27.9	23.2	21.9	19.1	25.1
2011/12	17.8	22.2	27.5	28.9	30.0	29.0	31.0	29.7	28.8	25.0	24.9	20.0	26.2
2012/13	20.8	22.7	24.7	29.4	30.3	27.2	30.2	31.6	28.9	25.6	23.7	21.8	26.4
2013/14	21.4	22.1	27.6	29.0	31.3	27.0	30.8	28.7	25.9	24.7	24.7	21.0	26.2
2014/15	20.0	23.1	28.4	30.8	27.6	29.4	30.1	31.0	28.5	26.9	27.8	20.3	27.0
2015/16	21.9	26.2	26.5	31.8	30.7	33.9	31.2	32.4	29.4	27.6	22.6	20.9	27.9
2016/17	20.0	24.2	28.0	30.7	30.3	31.1	27.7	26.6	29.4	26.5	23.8	22.7	26.8
						Potential evapotranspiration (mm)							
2008/09								113	123	108	83	68	
2009/10	78	112	159	150	161	195	121	134	118	82	68	72	1450
2010/11	39	108	163	200	169	171	132	119	113	78	78	71	1441
2011/12	77	114	162	176	194	163	169	139	138	114	108	80	1634
2012/13	99	140	146	190	203	132	168	153	128	100	93	82	1634
2013/14	89	112	146	170	194	151	165	103	104	98	87*	72*	1491
2014/15	81	103	147	176	149	159	153	143	118	101	97	69	1496
2015/16	80	123	129	179	190	212	166	158	137	106	86	74	1560
2016/17	82	114	154	182	175	177	133	100	128	91	80	76	1492
						Erfdeel							
Month	Jul	Aug	Sept	Oct	Nov	Des	Jan	Feb	Mar	Apr	May	Jun	Total/
						Rainfall (mm)							
2008/09								65	53	3	4	31	
2009/10	2	0	28	49	74	156	161	74	87	26	33	0	690
2010/11	0	0	0	13	74	155	50*	55*	60	53	51	40	551
2011/12	8	0	4	24	24	135	71	84	30	9	1	13	403
2012/13	2	2	58	56	61	136	94	41	14	55	1	0	542
2013/14	0	0	0	42	63	150	111	62	139	8	13	4	594
2014/15	0	24	0	20	87	85	85	45	69	53	1	6	475
2015/16	1	0	54	22	37	49	60	31	35	49	66	15	419
2016/17	35	0	0	47	220	67	96	237	14	23	7	3	749

						Mean maximum temperature (C)							
2008/09								27.7	27.6	27.0	22.7	19.6	
2009/10	18.2	22.5	28.2	28.0	27.4	31.1	27.7	30.4	29.2	25.7	24.2	20.9	26.1
2010/11	21.0	24.5	29.6	30.3	29.8	29.3	28.4	29.2	29.8	24.4	22.5	19.8	26.6
2011/12	18.6	22.8	27.7	29.0	30.2	29.1	31.6	29.8	29.8	26.2	26.2	20.0	26.8
2012/13	21.4	23.7	24.9	29.4	30.5	28.6	30.8	32.0	29.5	25.7	24.2	21.7	26.9
2013/14	21.8	22.4	27.6	29.5	30.8	27.9	31.2	29.6	26.6	25.5	24.9	21.2	26.6
2014/15	20.1	23.3	28.7	30.8	27.2	30.2	31.3	31.4	28.6	26.8	27.0	19.9	27.1
2015/16	21.2	26.8	26.7	32.0	30.8	34.0	31.8	33.1	30.1	27.6	23.3	21.4	28.2
2016/17	20.5	24.5	28.1	30.9	30.5	31.6	28.9	28.1	30.3	27.0	24.5	23.5	27.4
						Potential evapotranspiration (mm)							
2008/09								117	129	117	87	71	
2009/10	80	110	153	151	158	189	131	145	128	88	88	75	1496
2010/11	79	160	188	174	141	128	123	85	79	73	79	73	1524
2011/12	74	108	150	159	184	154	158	105	113	90	81	59	1435
2012/13	75	110	117	145	157	131	141	131	112	89	78	69	1420
2013/14	76	96	129	145	157	132	142	108	86	89	78	65	1303
2014/15	72	88	125	151	126	145	144	132	105	92	192	56	1428
2015/16	69	109	134	180	197	206	175	163	142	109	106	74	1664
2016/17	83	113	151	189	165	182	148	109	145	103	90	66	1544

* Suspect values due to malfunctioning of instruments.

Commercial farm equipment was used for all tillage and other actions with the exception of herbicides application during the growing seasons and grain harvesting. Herbicides were applied with knapsack sprayers during the active growing season. From 2008 to 2013 a no-till converted Gaspardo planter and from 2014 a Jumil no-till planter was used for seeding of all crops.

Crops were manually harvested and threshed with a small plot thresher and the yields calculated and adjusted for a moisture content of 12.5%. Nett plot sizes at Buffelsvallei were 396 m^2 for maize, 28.8 m^2 for sunflower, 14.4 m^2 for cowpea and 28.8 m^2 for millet. At Erfdeel, nett plot sizes were 180 m^2 for maize, 8.1m^2 for cowpea and 36 m^2 for millet. Rainfall use efficiencies were calculated for crop systems by dividing the grain yield by the accumulated rainfall from 1 July to 30 June of each year.

RESULTS AND DISCUSSION

Buffelsvallei

2008/09

The purpose of the 2008/2009 season was to create the crop rotational and no-till effects and results are thus presented separately from other seasons. The plant population density at harvest for the maize was 20 359 ha^{-1}, with a biomass yield of 10 749 kg ha^{-1}, a grain yield of 5 052 kg ha^{-1} and had a 57% soil cover in July after harvesting and flattening of the stubble.

Sunflower had a population density of 43 056 plants ha^{-1}, a biomass yield of 3 303 kg ha^{-1}, a grain yield of 1 389 kg ha^{-1} which left a 34% soil cover. The soyabean plant population was 301 250 ha^{-1} with a biomass yield of 1 778 kg ha^{-1}, and a grain yield of 1 043 kg ha^{-1} with a soil cover of 29% in July. The mean millet biomass yield was 12 407 kg ha^{-1} and resulted in a 62% cover of the soil during July.

2009/10 to 2016/17

Rainfall recorded in 2009/10, 2010/11, 2013/2014 and 2014/15 were similar to, or above the annual mean of about 600 mm (Table 3). In 2011/12, 2012/13 and 2016/17 less than the mean rainfall was recorded. Periods of no or low rainfall caused drought in all the growing seasons, with the exception of 2013/2014 and 2016/17, when little, if any drought occurred. Severe drought occurred especially in 2013/14, 2014/15 and 2015/16.

Results of the soil cover, plant population density, and yield of maize are shown in Table 4A where a legume, and in Table 4B where sunflower was included as rotational crops in the two of the three CA systems. Soil cover were similar for all crop systems in 2009/10 and were high, considering the minimum requirement of 30%. From 2010/11 to 2016/17 the soil cover of the three CA systems were several times higher than the cover of the CT mono-cropped maize. In nine out of a possible 16 cases, residue cover left by sunflower were below the 30% threshold set by the FAO to qualify for conservation agriculture.

From 2009/10 to 2015/16, maize plant population densities for the CA systems were lower than densities of the CT system in 5 out of a possible 35 instances. The mean decline in population in these cases was 13%. Lack of rain shortly after planting (7 days) caused failure to emerge and death of some seedlings in the CA systems in at least three instances.

The yield of maize was affected by crop system in six and five of the eight years where legume and sunflower crops were respectively included in the rotation systems. With a legume included in the rotation system, maize grain yields were not affected by crop production systems in 2009/10, 2011/12 and 2013/14. In 2012/13, 2014/15 and 2015/16 with its periods of severe mid-summer drought, the differences in yield between the conventional system and the three CA systems were remarkable. The yield of the CA systems, including maize monoculture and a legume and sunflower as rotational crops, were between 1518 and 2781 kg ha^{-1} higher than the yield of the CT system.

Yield differences also occurred among the CA systems. In five out of a possible 14 instances, the yield of maize in the millet-legume-maize no-till system was between 879 and 1479 kg ha^{-1} higher than the yield of the maize in the monocultured no-till and legume-maize no-till systems.

With sunflower as part of the rotation system instead of a legume, maize grain yields were not affected by any of the crop production systems in 2009/10, 2010/11 and 2013/14. In 2011/12 however, the yield of the maize in the sunflower-maize rotation under no-till was 1334 kg ha^{-1} lower than the yield of the CT system. As the sunflower crop failed in 2011/12, the rotation was fallow-maize for 2012/13 which resulted in similar yields as the monoculture maize system. In 2012/13, 2014/15, 2015/16 and 2016/17 the yield of maize in the no-till sunflower-maize and no-till millet-sunflower-maize systems were between 933 and 3503 kg ha^{-1} higher than the yield of the CT system.

Rainfall use efficiencies are shown in Tables 4A & 4B for the various systems. Calculated over seasons, the rainfall use efficiencies for maize in the CA systems were between 15 and 51% higher than the rainfall use efficiency of the CT monocultured maize. With the exception of one instance, the rainfall use efficiency of the CA systems never dropped below 5.51 kg ha^{-1} mm^{-1} while it was below this level in three out of eight seasons for the CT monocultured maize.

Table 4A The soil cover, plant population density, yield and rainfall use efficiency of maize as affected by a crop production system at Buffelsvallei with millet and a legume as rotational crops from 2009/10 to 2016/17

Season	Crop production system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Legume -maize, NT	Millet - legume - maize, NT
	Soil cover after planting (%)			
2009/10*	75^{A}**	73^{A}	83^{A}	82^{A}
2010/11	20^{B}	47^{A}	48^{A}	55^{A}
2011/12	24^{B}	61^{A}	57^{A}	64^{A}
2012/13	2^{B}	69^{A}	52^{A}	55^{A}
2013/14	7^{B}	54^{A}	19^{B}	38^{A}
2014/15	3^{C}	55^{A}	55^{A}	63^{A}
2015/16	13^{C}	66^{A}	37^{B}	66^{A}
2016/17	2^{B}	27^{A}	28^{A}	36^{A}
Mean	18	57	47	57
	Plant population density (m^{-2})			
2009/10	1.81^{A}	1.87^{A}	1.94^{A}	1.86^{A}
2010/11	2.31^{A}	2.42^{A}	2.33^{A}	2.45^{A}
2011/12	2.18^{A}	2.01^{B}	2.04^{AB}	1.97^{B}
2012/13	2.29^{A}	2.34^{A}	2.27^{A}	2.16^{A}
2013/14	2.72^{A}	2.77^{A}	2.69^{A}	2.78^{A}
2014/15	2.51^{A}	2.40^{A}	2.50^{A}	2.41^{A}

Season	Crop production system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Legume -maize, NT	Millet - legume - maize, NT
2015/16	2.14A	2.14A	2.22A	2.25A
Mean	2.28	2.28	2.28	2.27
		Yield (kg ha^{-1})		
2009/10	4050A	4417A	4939A	-
2010/11	5791B	5800B	6380B	7279A
2011/12	2399A	3068A	2211A	3037A
2012/13	1640B	3814A	4281A	4379A
2013/14	8686AB	8536B	9032AB	9780A
2014/15	2820B	6278A	6934A	7624A
2015/16	1086B	3867A	3701A	3595A
2016/17	6964C	7872B	7743B	8751A
Mean 2010/11 – 2016/17	4198	5605	5755	6349
		Rainfall use efficiency (kg ha^{-1} mm^{-1})		
2009/10	6.11	6.66	7.45	
2010/11	9.65	9.67	10.63	12.13
2011/12	5.98	7.65	5.51	7.57
2012/13	3.03	7.05	7.91	8.09
2013/14	14.26	14.02	14.83	16.06
2014/15	4.07	9.06	10.00	11.00
2015/16	2.38	8.46	8.10	7.87
2016/17	12.35	13.96	13.73	15.52
Mean 2010/11 – 20116/17	7.39	9.98	10.10	11.18

¢ Conventional tillage * Soil cover in 2009/10 was measured before planting.

¢¢ No-till ** Values in a row followed by different letters are significantly different.

Table 4B The soil cover, plant population density, yield and rainfall use efficiency of maize as affected by a crop production system at Buffelsvallei with millet and sunflower as rotational crops from 2009/10 to 2016/17

Season	Crop production system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Sunflower -maize, NT	Millet - sunflower - maize, NT
		Soil cover after planting (%)		
2009/10*	75A**	73A	83A	82A
2010/11	20B	47A	22B	38A
2011/12	24B	61A	20B	28B
2012/13	2D	69A	22C	34B
2013/14	7C	54A	28B	33AB
2014/15	3C	55A	20B	30B
2015/16	13B	66A	29B	59A
2016/17	2B	27A	15AB	23AB

Season	Crop production system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Sunflower -maize, NT	Millet - sunflower - maize, NT
Mean	18	57	30	41
	Plant population density (m^{-2})			
2009/10	1.81^{A}	1.87^{A}	1.94^{A}	1.86^{A}
2010/11	2.31^{B}	2.42^{AB}	2.33^{AB}	2.45^{A}
2011/12	2.18^{A}	2.01^{AB}	2.04^{AB}	1.85^{B}
2012/13	2.29^{A}	2.34^{A}	2.27^{A}	2.16^{A}
2013/14	2.72^{A}	2.77^{A}	2.73^{A}	2.78^{A}
2014/15	2.51^{A}	2.40^{AB}	2.18^{B}	2.45^{AB}
2015/16	2.14^{A}	2.14^{A}	1.71^{B}	1.98^{AB}
Mean	2.28	2.28	2.17	2.22
	Yield (kg ha^{-1})			
2009/10	4050^{A}	4417^{A}	4291^{A}	-
2010/11	5791^{A}	5800^{A}	5824^{A}	6298^{A}
2011/12	2399^{AB}	3068^{A}	1734^{B}	2230^{AB}
2012/13	1640^{B}	3814^{A}	3487^{A}	3579^{A}
2013/14	8686^{A}	8536^{A}	8271^{A}	8944^{A}
2014/15	2820^{C}	6278^{A}	4338^{B}	6323^{A}
2015/16	1086^{B}	3867^{A}	3185^{A}	2921^{A}
2016/17	6964^{B}	7872^{A}	6858^{B}	7897 ^{A}
Mean 2010/11 – 2016/17	4198	5605	4814	5456
	Rainfall use efficiency (kg ha^{-1} mm^{-1})			
2009/10	6.11	6.66	6.47	
2010/11	9.65	9.67	9.71	10.50
2011/12	5.98	7.65	4.32	5.56
2012/13	3.03	7.05	6.45	6.62
2013/14	14.26	14.02	13.58	14.69
2014/15	4.07	9.06	6.26	9.12
2015/16	2.38	8.46	6.97	6.39
2016/17	12.35	13.96	12.16	14.00
Mean 2010/11 – 2016/17	7.39	9.98	8.49	9.55

¢ Conventional tillage ¢¢ No-till * Soil cover in 2009/10 was measured before planting. * Soil cover in 2009/10 before planting. ** Values in a row followed by different letters are significantly different.

Grain and biomass yields of the legumes showed considerable seasonal variation (Table 5). In 2010/11 cowpea grain rotted due to rain during harvesting, resulting in a low yield. In 2013/14 and 2014/15 late rain again caused cowpea seed to rot with a total yield loss. Despite severe drought in 2011/12 and 2012/13, cowpeas gave a reasonable yield. Yields from sunflower crops were more stable than the legume yields. Millet yields also varied considerably from season to season.

Table 5 Plant population density (m^{-2}) and yield (kg ha^{-1}) of rotational crops at Buffelsvallei

Season	Legume*			Sunflower			Millet
	Density	Grain yield	Bio-mass	Density	Grain yield	Bio-mass	Bio-mass
2008/09	30.1	1043	2821	4.31	1389	3303	12407
2009/10	33.0	1608	3844	4.22	2257	6399	4051
2010/11	15.7	289	6467	3.27	1068	3561	3982
2011/12	11.0	918	4051	-	-	-	4437
2012/13	7.8	1034	2593	3.39	1398	3965	6163
2013/14	12.9	0**	5699	3.80	2592	7604	7381
2014/15	11.1	0**	5514	4.10	1838	5856	9775
2015/16	10.9	1420	3562	3.81	***	***	5247
2016/17	12.3	2342	6163	4.00	-	-	16284

* Soyabean in 2008/09 and 2009/10 and cowpeas since 2010/11.

** No yield as seed rotted due to late rain.

*** Crop failed.

Grading of the maize grain and parameters for milling quality for some selected seasons are shown in Table 6. In general, and with the exception of the 2012/13 season, lower grain grading of samples were more frequent in conventionally produced maize than those produced with no-till and crop rotation. The milling index was affected in two out of the five seasons with rotated maize having similar or higher indexes than monocultured produced grain.

Kernel size (percentage ≥8 mm) was affected in two out of four seasons. Rotated maize grain had similar or higher percentages of kernels ≥8 mm than grain samples from monocultured maize. The differences were probably too small to be of any practical value.

Table 6 Maize grading and milling quality as affected by crop production systems at Buffelsvallei

Season	Crop production system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Leg/sunflower - maize, NT	Millet - soyabean/sunflower -
	Grading percentage (Percentage samples graded as WM1)			
2009/10	0	0	0	0
2010/11	25	75	100	100
2011/12	75	100	100	88
2012/13	75	50	63	75
2013/14	75	75	88	88
2014/15	0	0	0	0
2015/16	100	100	100	100
	Milling index			
2009/10*	93.10 A	92.70 A	96.20 A	95.10 A
2010/11	74.50 A	75.20 A	73.00 A	79.40 A
2011/12	81.00 B	80.30 B	86.70 A	84.50 AB
2012/13	86.00 B	90.00 AB	95.00 B (Leg.) 96.00 A (Sun.)	95.00 B (Leg.) 95.00 A (Sun.)
2013/14	83.00 A	78.00 A	81.00 A	77.00 A
2014/15	10.00	10.00	10.00	10.00
	Stress cracks (%)			
2009/10	3.00 A	4.00 A	1.75 A	3.75 A
2010/11	0.00 A	1.00 A	2.75 A	2.75 A
	Kernels ≥8 mm (%)			
2009/10	79.20 A	82.00 A	82.40 A	81.90 A
2010/11	83.80 BC	82.30 C	86.70 A B	89.70 A
2011/12	55.30 A	63.40 A	67.60 A	67.50 A
2012/13	90.00 A	85.80 A	80.80 A	80.80 A
2013/14	93.30 B	94.40 B	95.00 B (Leg.) 95.60 A (Sun.)	94.20 B (Leg.) 95.00 A (Sun.)
	Milling yield (%)			
2009/10	77.2 A	76.2 A	77.8 A	77.8 A
2010/11	78.3 A	77.9 A	78.0 A	77.8 A
	Whiteness index			
2009/10	87.8 A	87.0 A	87.4 A	87.7 A
2010/11	88.8 AB	88.7 AB	89.0 A	88.1 B
2011/12	73.3 A	74.2 A	73.5 A	73.8 A
2012/13	77.2 A	77.2 A	75.5 B (Leg.) 75.3 A (Sun.)	76.5 B (Leg.) 75.0 A (Sun.)
2013/14	68.9 A	67.8 AB	66.1 B (Leg.) 66.9 A (Sun.)	69.3 A (Leg.) 68.8 A (Sun.)

¢ Conventional tillage ¢¢ No-till. ** Values in a row followed by different letters are significantly different.

Soil strength

Soil strength in 2010, 2013 and 2014 for the four crop systems at Buffelsvallei is shown in Table 7. Soil strength varied with time with no clear pattern. As expected however, soil strength in the upper 300 mm of the profile for the CT system was lower than the strength of the CA systems in all seasons. Soil strength values deeper than 10 cm in the profile of the CA systems were high compared to that of the CT systems and most often exceeded 2000 kPa, a threshold where root growth is usually reduced by about 50%.

Table 7 Soil strength in kPa for crop systems at Buffelsvallei from 2010 to 2014

Soil depth (cm)	Crop system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Soyabean/sun-flower -maize, NT	Millet - soyabean/sunflower
		March 2010		
0 - 10	1042	1015	1015	1079
10 - 20	1782	1544	2398	2469
20 - 30	2004	2477	2872	2926
30 - 40	2475	3275	3314	3198
		March 2013		
0 - 10	241	441	401	469
10 - 20	1162	1710	1829	1787
20 - 30	1567	2260	2722	2454
30 - 40	1978	2647	3110	2328
		March 2014		
0 - 10	296	697	640	608
10 - 20	572	2046	1423	1592
20 - 30	1463	2738	2078	2691
30 - 40	2735	2558	3016	3284

Soil analyses for the 0-5 cm depth at Buffelsvallei

It is known that the upper layer of the profile of no-till soil get enriched with nutrients over time when compared to that of tilled soil. Table 7.1 shows the pH, P, K, Ca, Mg, Na and organic carbon content of the 0-5 cm soil layer for the different crop systems since 2013 when some differences became significant.

Excluding the results of 2017, the three CA systems had similar or higher pH, phosphorus, potassium, calcium, magnesium and sodium contents than the monocultured maize CT system. This indicates enrichment of this soil layer in the CA systems compared with the conventional system. The lack of differences in 2017 cannot be logically explained.

Compared to initial carbon content of the 0-5 cm soil layer in 2008 (Table 2), it increased between 17 to 45% for the CA systems, while the carbon content of the CT system stayed unchanged. However, from 2013 to 2017 the carbon content of the 0-5 cm soil layer increased with 0.030, 0.032, 0.033 and 0.034 percentage points for the CT, no-till monocultured maize, no-till sunflower/legume-maize and no-till millet-sunflower/legume-maize systems respectively.

Table 7.1 The pH, phosphorus, potassium, calcium, magnesium, sodium and organic carbon content of the 0 – 5 cm soil layer at Buffelsvallei for crop systems, sampled during the winters of 2013 to 2017

Sampling year	Crop system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Soyabean/sunflower -maize, NT	Millet - soyabean/sunflower maize, NT
			pH	
2013	4.80 B	5.19 AB	5.44 A	5.39 A
2014	4.70 B	5.11 A	5.45 A	5.25 A
2015	4.70 B	5.50 A	5.81 A	5.78 A
2016	4.73 B	5.48 A	5.74 A	5.70 A
2017	4.75 C	5.08 B	5.61 A	5.51 B
			P (mg kg^{-1})	
2013	41.5 AB	45.3 AB	40.3 B	49.1 A
2014	44.3 A	40.9 A	42.9 A	44.3 A
2015	41.3 AB	40.3 B	42.9 B	50.0 A
2016	44.3 A	40.5 A	45.4 A	50.7 A
2017	45.8 A	51.3 A	48.8 A	53.0 A
			K (mg kg^{-1})	
2013	142 B	180 AB	193 AB	217 A
2014	125 B	146 AB	164 AB	187 A
2015	174 B	197 AB	212 AB	264 A
2016	143 B	202 AB	178 AB	209 A
2017	166 A	178 A	185 A	245 A
			Ca (mg kg^{-1})	
2013	277 B	353 AB	336 AB	357 A
2014	286 B	353 AB	345 AB	350 A
2015	240 B	327 AB	323 A	364 A
2016	269 B	328 AB	335 A	367 A
2017	292 A	307 A	344 A	350 A

			Mg (mg kg^{-1})	
2013	60.3 ^{B}	80.3 ^{A}	83.8 ^{A}	93.9 ^{A}
2014	67.8 ^{B}	92.7 ^{A}	98.2 ^{A}	103.4 ^{A}
2015	63.3 ^{C}	121.8 ^{AB}	109.7 ^{B}	127.4 ^{A}
2016	66.5 ^{C}	119.0 ^{AB}	114.8 ^{B}	127.1 ^{A}
2017	70.8 ^{A}	101.5 ^{A}	105.6 ^{A}	119.2 ^{A}
			Na (mg kg^{-1})	
2013	9.0 ^{B}	10.2 ^{AB}	11.3 ^{AB}	11.5 ^{A}
2014	7.3 ^{A}	6.8 ^{A}	8.2 ^{A}	7.9 ^{A}
2015	0	0	0	0
2016	0.8 ^{B}	2.5 ^{A}	4.4 ^{A}	4.3 ^{A}
2017	5.3 ^{A}	3.0 ^{A}	3.8 ^{A}	3.4 ^{A}
			Organic C (%)	
2013	0.34 ^{B}	0.47 ^{AB}	0.43 ^{B}	0.54 ^{A}
2014	0.38 ^{B}	0.41 ^{B}	0.46 ^{B}	0.55 ^{A}
2015	0.38 ^{C}	0.64 ^{AB}	0.54 ^{BC}	0.70 ^{A}
2016	0.42 ^{B}	0.57 ^{AB}	0.49 ^{B}	0.61 ^{A}
2017	0.47 ^{D}	0.55 ^{C}	0.58 ^{B}	0.68 ^{A}

** Values in a row followed by different letters are significantly different.

Water infiltration rate

The water infiltration rate usually increases where the soil is left undisturbed and covered with plant residue. Infiltration rates for the various crop systems was measured during March 2015. A single ring of 154 mm diameter was used and the depth of the water applied was 27 mm. This method is considered an informal indication of the infiltration rate. The results are however, remarkable.

The time for 27 mm of water to infiltrate took 17.4 minutes in the monocultured plough system, while it took between 3.2 and 6.7 minutes in the no-till systems. Due to the slow infiltration of the monocultured plough system, runoff occurred during several of the rainstorms in at least 2012/13 and 2014/15 as suggested by visible soil erosion. No visible erosion was evident in the no-till systems suggesting that all the water infiltrated.

Erfdeel

2008/09

Rainfall was measured since 21 January 2009. From this date until the end of April 2009, 251 mm rainfall was recorded. The plant density for maize was 28 669 plants ha^{-1}. The estimated biomass yield was 8 619 kg ha^{-1} and the mean grain yield 4 051 kg ha^{-1}. Similar maize yields were recorded on the tilled and untilled soil. After flattening the stubble, the mean soil cover for maize was 50%.

The mean sunflower biomass and grain yield was 4 615 and 1 707 kg ha^{-1} respectively with 36% soil cover and a population density of 28 098 plants ha^{-1}. The soyabean crop suffered damage by birds and other wildlife. The final plant population was 244 400 ha^{-1}, far below the optimum. Soyabean had an estimated biomass yield of 3 068 kg ha^{-1} and a grain yield of 2 111 kg ha^{-1} and left a 28% soil cover.

2009/10

Rainfall recorded for 2009/2010 were above the long-term mean with the highest monthly amount in December (Table 3). The spread during the season was unfavourable which resulted in drought.

Growth of all crops in 2009/2010 were visibly restricted by soil acidity, despite the application of lime and gypsum in 2008/2009. Results on the soil cover, plant population density and yield of maize at Erfdeel are shown in Table 8. Soil cover for monocultured no-till maize was higher than that of the other crop systems. The unexpectedly low value for millet was most likely due to the use of a "rolmoer" to flatten standing stover. This caused shredding of stover that could be easily blown away by wind or buried beneath the soil surface. Neither the plant population density, nor the grain yield of maize was affected by cropping system.

Despite measures to protect it, the soyabean crop was damaged by wind and wildlife to such extent that no significant yield could be measured. The sunflower yield was also restricted by the acid soil and bird damage. It was decided to replace both sunflower and soyabean with cowpeas. Despite the drawbacks, the sunflower crop still produced a reasonable yield.

2010/11

Uneven growth of maize within plots during 2009/10 suggested that soil acidity were still crop restrictive in some areas. This was confirmed with a soil analyses. An amount of 4.2 ton dolomitic lime (Ca: 19.5%; Mg: 11.7%) plus 2.5 ton of gypsum ha^{-1} was applied during August 2011 and the whole plot area ploughed to a depth of 250 mm during August 2010. To restrict wind erosion maize stubble were spread on the soil after ploughing.

Rainfall during 2010/2011 was above the long-term mean (>650 mm) although accurate values are not available for the months of December and January. The spread was favourable with only a short period of drought during January.

Crops visually responded to the liming by growing vigorously. Results on the soil cover, plant population density and yield of maize at are shown in Table 8. Notwithstanding a low cover, wind erosion was controlled effectively. Due to the ploughing of the whole area, a statistical comparison of plant population and yield is not possible. Inspection during the growing season revealed the presence of a compacted plough layer at 30 cm depth which restricted root development. Despite this restriction, the yield of maize was high and exceeded that of the adjacent commercial field.

Cowpeas was grown as the rotational crop. A relatively high biomass was recorded, but the grain yield was low (Table 9). Most of seed rotted in their pods or shattered due to prolonged rain and wet conditions at maturity and hence the low yield.

Results from 2011/12 to 2016/17

During 2011/12, 2014/15 and 2015/16 seasons rainfall was below the long term mean. In 2012/13 and 2013/14 respectively, rainfall was similar to the long term mean and in 2016/17, rainfall above the mean were recorded. Periods of drought, which varied in length and intensity, developed during parts of January, February, March and even April of almost all seasons. Drought during January and February caused the most visible water stress in crops.

The soil cover (Table 8) for all systems was at, or below the 30% threshold set for Conservation Agriculture in 2011/12. It exceeded this threshold from 2012/13 to 2015/6 for all crop systems except the no-till monocultured maize system in 2014/15 and monocultured CT system in 2015/16. Soil cover for the CA systems with rotational crops included, were similar or higher than those of the mono-cropped systems.

Visually the soil surface, where legumes were grown, was more stable and resistant to wind erosion prior to planting than where maize was grown. This observation was made annually even after the crop residue was flattened with a “rolmoer”, which disturbed the soil surface slightly.

As the soil was ripped 55 cm deep on the intended planting rows during August 2011 to alleviate the compacted layer found in 2010/11, a statistical comparison between no-till and tillage treatments for 2011/12 was not possible. However, the yield of maize produced in rotation with cowpeas, exceeded the yield of the two systems where maize was grown in monoculture by 45% or 2 062 kg ha^{-1}. This confirms the advantage of crop rotation with a legume on sandy soils, on the yield of maize is present in most seasons.

From 2012/13 to 2015/16, the yield of the maize crops in the CA systems never significantly exceeded the yield of the CT monocultured maize system. In three out of a possible 12 instances, the CA yields were significantly lower than the yields of the CT monocultured maize system. In nine instances, the yields were similar.

Crop rotation played a significant role in the success or failure of CA on the sandy soil at Erfdeel. Compared over the period of four seasons (2012/13 to 2015/16), the mean yield of the no-till monocultured maize was 37% lower, the mean yield of the no-till millet - legume - maize system was 20% lower, while the mean yield of the legume - maize no-till system was similar to the maize yield of the CT monocultured maize system.

Rainfall use efficiencies are shown in Table 8. Calculated over time from 2012/13 to 2015/16, the rainfall use efficiency for maize in the no-till legume - maize system was similar to the efficiency of the CT system. The rainfall use efficiencies of the no-till monocultured and no-till millet – legume - maize systems were 36 and 19% respectively lower than the rainfall use efficiency of the CT system.

Cowpea and millet biomass yields are shown in Table 9. Cowpea grain yields varied from 800 to 2 700 kg ha^{-1} and biomass yields between 3 000 and 9 400 kg ha^{-1}. Rainfall after ripening of the seed in 2010/11 caused rotting, which lowered the grain yield. In 2013/14 and 2014/15, the grain yield was completely lost due to rotting. Millet biomass yields varied between 3 200 and 13 879 kg ha^{-1}.

Grading and milling quality of the maize are shown in Table 10. Grain grading was affected in three of the four seasons of measurement. No clear pattern on how it was affected by crop systems exists. The milling and whiteness indices were unaffected by crop systems, while the kernel size was affected in one season only with rotated maize having a similar or larger size than the monocultured systems.

Table 8 Soil cover, plant population density and yield of maize as affected by crop production system at Erfdeel

Season	Crop production system			
	Monocultured maize, CT ¢	Monocultured maize, NT ¢¢	Legume -maize, NT	Millet - legume - maize, NT
	Soil cover after planting (%)			
2009/10*	38^{B**}	57^{A}	30^{B}	29^{B}
2010/11	15	15	15	15
2011/12	18^{B}	23^{AB}	32^{A}	33^{A}
2012/13	35^{C}	50^{BC}	58^{AB}	64^{A}
2013/14	38^{BC}	36^{C}	55^{A}	52^{AB}
2014/15	31^{BC}	21^{C}	49^{B}	72^{A}
2015/16	21^{C}	49^{B}	52^{B}	70^{A}
Mean $_{2012/13 – 2015/16}$	35	36	54	63
	Plant population density (m^{-2})			
2009/10	2.41^{A}	2.62^{A}	2.30^{A}	2.57^{A}
2010/11	2.42	2.34	2.36	2.39
2011/12	2.76^{B}	2.84^{A}	2.82^{AB}	2.77^{AB}
2012/13	2.07^{A}	2.27^{A}	2.25^{A}	2.24^{A}
2013/14	2.46^{AB}	2.43^{B}	2.54^{A}	2.53^{A}
2014/15	2.68^{A}	2.70^{A}	2.77^{A}	2.91^{A}
2015/16	2.53^{A}	2.38^{A}	2.54^{A}	2.21^{A}
Mean $_{2012/13 – 2015/16}$	2.44	2.45	2.53	2.51
	Yield (kg ha^{-1})			
2009/10	3418^{A}	3255^{A}	3712^{A}	3973^{A}
2010/11	7552^{A}	6658^{A}	7112^{A}	6334^{A}
2011/12	4782^{B}	4289^{B}	6557^{A}	6638^{A}
2012/13	5641^{A}	3721^{B}	5289^{A}	4850^{AB}
2013/14	5333^{AB}	2089^{B}	5521^{A}	4003^{AB}
2014/15	5713^{A}	4117^{B}	6568^{A}	4433^{B}
2015/16	3928^{A}	3016^{A}	3258^{A}	3286^{A}
Mean $_{2012/13 – 2015/16}$	5154	3236	5159	4143
	Rainfall use efficiency (kg ha^{-1} mm^{-1})			
2009/10	4.95	4.72	5.38	5.76
2010/11	13.71	12.08	12.91	11.50
2011/12	11.87	10.64	16.27	16.47
2012/13	10.41	6.87	9.76	8.95
2013/14	8.98	3.52	9.29	6.74
2014/15	12.18	8.78	14.00	9.45
2015/16	9.37	7.20	7.78	7.84
Mean $_{2012/13 – 2015/16}$	10.24	6.59	10.21	8.25

¢ Conventional tillage ¢¢ No-till

* Soil cover in 2009/10 was measured before planting.

** Values in a row followed by different letters are significantly different.

Table 9 Plant population density (m^{-2}) and yield (kg ha^{-1}) of rotational crops at Erfdeel

Season	Legume			Sunflower			Millet
	Density	Grain yield	Biomass**	Density	Grain yield	Biomass**	Biomass**
2008/09	24.4	2111	3068	2.81	1707	4605	13700
2009/10	-	-	-	1.87	1208	4063	6173
2010/11	14.3	842	9384	-	-	-	6486
2011/12	11.0	1231	6435	-	-	-	6139
2012/13	12.0	2155	7670	-	-	-	4722
2013/14	13.0	0*	6271	-	-	-	7188
2014/15	8.0	0*	1482	-	-	-	13879
2015/16	12.0	2701	4898				5611

**Late rain caused seed rotting and total loss of grain yield and some biomass.*

***Not adjusted for moisture content.*

As indicated in the materials and methods, treatments were altered to determine the optimum depth of soil disturbance for maize production. The results are shown in Figure 1. The yield of maize increased with 2.21 t ha^{-1} by disturbing the soil to a depth of 40 cm and levelled off.

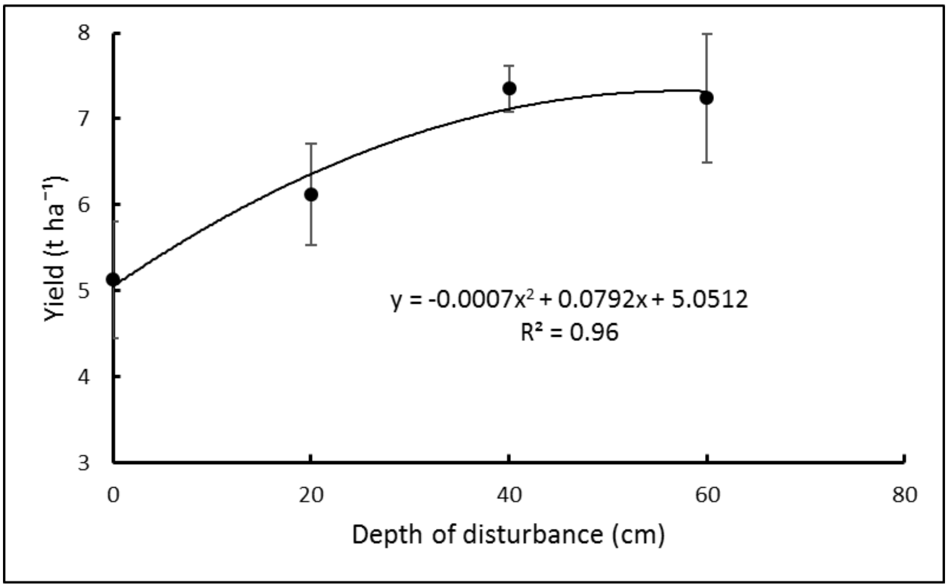

Figure 1 The yield response of maize to the depth of soil disturbance at Erfdeel in 2016/2017.

Soil Strength

Soil strength versus soil depth at Erfdeel for the four crop systems is shown in Table 11. The same pattern was found in the respective seasons. From the soil surface to 100 mm depth, the soil strength was similar for all crop systems. From 101 to 500 mm deep, the soil strength of the CT systems was lower than that of the NT crop systems, as expected. From 500 to 700 mm deep, the soil strength of the CT system was similar or lower than the strength of the no-till systems.

Table 10 Maize milling quality as affected by crop production systems at Erfdeel

Season	Crop production system			
	Monocultured	Monocultured	Legume -maize, NT	Millet - legume -
	Grading percentage (Percentage samples graded as WM1)			
2010/11	100	100	75	75
2011/12	100	100	100	100
2012/13	50	50	75	100
2013/14	75	50	100	75
2014/15	-	-	-	-
	Milling index			
2009/10*	105.0^{A**}	103.0^{A}	104.0^{A}	105.0^{A}
2010/11	85.0^{A}	84.0^{A}	86.0^{A}	85.0^{A}
2011/12	80.1^{A}	85.2^{A}	79.4^{A}	83.6^{A}
2012/13	99.5^{A}	98.2^{A}	101.8^{A}	95.4^{A}
2013/14	88.8^{A}	88.1^{A}	91.5^{A}	95.3^{A}
2014/15	-	-	-	-
	Stress cracks (%)			
2009/10	3.5^{A}	0.7^{A}	4.5^{A}	3.5^{A}
2010/11	1.5^{A}	3.0^{A}	1.0^{A}	1.0^{A}
2011/12	na			
	Kernels ≥8 mm (%)			
2009/10	83.9^{A}	83.6^{A}	81.3^{A}	83.2^{A}
2010/11	93.3^{A}	91.4^{A}	92.7^{A}	93.6^{A}
2011/12	92.6^{AB}	91.3^{B}	95.0^{A}	94.7^{A}
2012/13	78.9^{A}	79.4^{A}	83.4^{A}	81.4^{A}
2013/14	94.1^{A}	93.2^{A}	90.6^{A}	95.4^{A}
2014/15	-	-	-	-
	Milling yield (%)			
2009/10	78.9^{A}	79.3^{A}	78.0^{A}	78.3^{A}
2010/11	78.0^{A}	77.2^{A}	77.1^{A}	77.3^{A}
2011/12	na			
	Whiteness index			
2009/10	87.1^{A}	86.6^{A}	87.2^{A}	87.3^{A}
2010/11	90.2^{A}	91.0^{A}	90.1^{A}	90.3^{A}
2011/12	73.2^{A}	72.9^{A}	72.5^{A}	73.7^{A}
2012/13	75.4^{A}	74.9^{A}	75.3^{A}	76.1^{A}
2013/14	68.6^{A}	65.6^{A}	68.5^{A}	68.3^{A}
2014/15	-	-	-	-

¢ Conventional tillage

¢¢ No-till

** Values in a row followed by different letters are significantly different.

Table 11 Soil strength in kPa at Erfdeel March 2013

Soil depth (mm)	Crop system			
	Monocultured maize, CT			
	March 2013			
0 - 100	219	250	289	280
101 - 200	508	917	975	789
201 - 300	685	1180	1233	1071
301 - 400	935	1754	1937	1770
401 - 500	1086	2002	2212	1894
501 - 600	1451	1985	1883	1742
601 - 700	2219	1874	1773	2036
	March 2014			
0 - 100	459	511	509	525
101 - 200	984	1696	1291	1579
201 - 300	1372	2286	1756	1992
301 - 400	1682	2722	2645	2571
401 - 500	1834	2371	2855	2740
501 - 600	1815	1773	2355	2048
601 - 700	1683	1732	2082	1808
	April 2015			
0 - 100	488	587	591	672
101 - 200	1277	1792	1775	1794
201 - 300	1660	2151	2073	1955
301 - 400	1733	2283	2431	2201
401 - 500	2049	2289	2279	2336
501 - 600	1860	1987	2011	2097
601 - 700	1899	1824	1805	1494

Soil analyses for the 0 - 5 cm depth and infiltration rate at Erfdeel

Analyses of the 0 - 5 cm soil layer showed no difference between the conventional and CA crop systems. Mean pH, plant nutrients and carbon contents as reported in Table 2 for the 0 - 5 cm depth of Erfdeel is thus applicable.

Due to the lack of a slope and the high water infiltration rate of the extremely sandy soil, the infiltration rate was regarded as not influencing the hydrology and subsequently not measured.

GENERAL DISCUSSION AND CONCLUSIONS

The occasional lower than intended maize plant population of the CA systems is in agreement with farmers' experience that to obtain a target plant population, can sometimes be difficult. The yield of maize was most likely not significantly affected by the lower density as the CA yield were similar or, higher than the yield of the conventional system. However, crop establishment also depends on the type and adjustment of equipment used for planting such as tines or coulters fitted on planters. Soil types may also require different equipment for optimal crop establishment which is a topic for further research.

The maize yield results at Buffelsvallei indicate that the soil and climate are favourable for the application of CA. The increased CA yield response of 34% were mainly caused by the no-till action, followed by a further 3 to 17% due to crop rotation with a legume. Sunflower as the rotational crop did not result in any further yield improvement, but had a neutral reducing effect on the increase caused by the no-till. The importance of three crops in rotation, rather than two, is also clear from the results and should be pursued. Testing of different no-till crop rotation systems, with or without the inclusion of cover crops and animal production for their profitability and production risk, in this environment is needed.

The occurrence of one or more period of drought during the months of January, February and March is a regular phenomenon of the weather of the region and were present in all growing seasons with the exception of 2013/14 and 2016/17. Crop systems that are able to mitigate this drought would be the best suited for this environment. The superiority of the CA crop systems as judged by the yield and rainfall use efficiencies of maize at Buffelsvallei in 2012/13 and again in 2014/15 when severe midsummer drought occurred, is evident. This is probably caused by the higher water infiltration rate of the of the CA soil securing more water for crop use than in the CT system, where runoff occurred due to the formation of infiltration crusts. Infiltration crust formation is prevented or restricted by a soil cover of crop residues and increased organic carbon content. Indications are that the CA crop systems have improved the hydrology of the soil in favour of grain production at Buffelsvallei. Although water dynamics were not measured, the often-visible difference in runoff, intensity of water stress and the measured water infiltration rate difference between the CT and CA systems suggested a difference in the availability of water, or the ability to take up water from the soil.

Other factors than water also played an important role in the observed yield differences. Root and stem rot of maize have been identified in a separate project as two of them. Others still need to be identified.

Soil strength, as an indication of soil compaction, did not correlate with yield at Buffelsvallei suggesting that it was not yield limiting or, that the negative effect that it might have was overcome by other factors. Water infiltration rate, as a relative measure, appears to be a good indicator of soil improvement where the land has a slope and the soil easily forms an infiltration crust.

The effect of CA on the yield of maize on the extreme sandy soil of Erfdeel is in contrast to the results of Buffelsvallei. CA, especially no-till had limited success at Erfdeel. In general, no-till resulted in decreased maize yields and rainfall use efficiencies. This decrease was neutralised only by the rotational yield improvement of a legume, in this case cowpeas. Inclusion of a third crop did not cause any improvement of yields either. The tendency of the sandy soil to compaction leading to restricted root growth, probably neutralised any other soil improvement caused by CA. Improvements in the hydrology due to CA is also unlikely as the soil has a high infiltration rate, infiltration crusts do no develop on this soil and runoff seldom, if ever, occurs. The high rainfall use efficiency of the CT system at Erfdeel compared to that of Buffelsvallei, also indicates that interception of rainfall is high and that improvement of it, is unlikely. The stark difference of the results between the two trial locations indicates that the extrapolation of results and propagation of some CA practices across environments, should be done with caution.

A major part of the soil of the maize producing area has a sandy texture. Future CA research should thus concentrate on sandy and loamy sand soils (clay contents lower than 16%) as the effects of CA principles on the soil physical, chemical and microbiological variables are unclear, especially the role of nematodes and related disease complexes are still unknown. However, the subsoil and its characteristics also plays a role in the success of CA, especially no-till. Due to the compaction problem of sandy textured soils, the absolute minimum depth of disturbance during planting in CA crop systems should be determined for the major soil forms and -families.

The relatively fast improvement in the organic carbon content of the upper soil layer of the CA systems is of importance. One of the benefits of CA is an enrichment of the soil with organic carbon. Where millet, as cover crop was part of the crop system, a significant improvement was reached in only four years. It relates to the improved infiltration rate and contributed to the higher yields of the CA systems in some seasons and emphasise the importance of the inclusion of a high yielding cover crop in CA systems. If and how the organic carbon content of the subsoil will change is still unknown.

PROJECT OUTPUTS since 2011

Scientific Publications

NEL A.A. & LAMPRECHT, S.C., 2011. Crop rotational effects on irrigated winter and summer grain crops at Vaalharts. *SA Journal of Plant and Soil*, 28: 127 - 133.

Semi-scientific publication

NEL, A.A. & DEALE, W., 2012. Gewas- en grondbewerkingstelsels. / Crop and soil cultivation systems, p 74 - 83. *MIG 2012*. Compiled by ARC-Grain Crops Institute, Potchefstroom.

NEL, A.A. & DEALE, W., 2012. Trekkrag toets op grondbewerking implemente, p 74 - 87. / Testing of drawbar power for tillage implements, p 84 - 87. *MIG 2016*. Compiled by ARC-Grain Crops Institute, Potchefstroom.

NEL, A.A. & DEALE, W., 2013. Grondbewerking en bewaringsboerdery, p 91 - 97. / Soil cultivation and Conservation Agriculture, p 98 - 104. *MIG 2013*. Compiled by ARC-Grain Crops Institute, Potchefstroom.

NEL, A.A. & DEALE, W., 2013. Trekkrag toets op grondbewerking implemente, p 105 - 107. / Testing of drawbar power for tillage implements, p 108 - 110. *MIG 2016*. Compiled by ARC-Grain Crops Institute, Potchefstroom.

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NEL, A.A. & DEALE, W., 2017. Trekkrag toets op grondbewerking implemente, p 102 - 104. / Testing of drawbar power for tillage implements, p 105 - 107. *MIG 2016*. Compiled by ARC-Grain Crops Institute, Potchefstroom.

Conferences (papers)

NEL, A.A., 2014. Maize yield as affected by conservation agriculture systems on a Hutton soil in the North West Province. Combined Congress, Grahamstown, pg 130. 20 - 23 January 2014.

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NEL, A.A., 2014. Bewaringsboerdery by saaiboerdery. *Radio RSG Landbou*, 4 Augustus 2014.

Visitors

Twelve INTA and Argentinian agriculturists visited the conservation agriculture trial on 21 May 2013.

Forty local farmers visited the conservation agriculture trial during March 2014.

Nineteen local farmers visited the conservation agriculture trial during February 2015

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Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser (kg ha^{-1})			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
Maize									
2008/09	PAN 6Q-521 R	20 000	26 Nov. 2008	55 + 0	12	8	Dual Gold 500 mℓ ha^{-1}	Roundup 2.5 ℓ ha^{-1} on 18 Dec. 2008. 6 Jan. 2009. Manual 15 Jan. 2009	None
2009/10	PAN 6Q-521 R	20 000	16 Nov. 2009	17 + 34	11	6	Dual Gold 600 mℓ ha^{-1}	Roundup 2.5 ℓ ha^{-1}, Jan. 2009	None

Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser (kg ha^{-1})			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
2010/11	PAN 6P-563 R	24 500	19 Nov. 2010	27 + 70	18	9	Gramoxone 3 ℓ, Agril ha^{-1}, 21 Oct. 2010. Dual Gold 600 mℓ ha^{-1}, 19 Nov. 2010	Roundup 2.5 ℓ ha^{-1}, Booster, 14 Dec. 2010. Roundup 2.25 ℓ, Dual 250 mℓ ha^{-1}, Booster, Bladbuff 10 Jan. 2011. Manual 30 Nov. 2010, 10 & 17 Jan 2011. Roundup mix 2 ℓ ha^{-1} 10 May 2011	Kombat stalk borer granules 4 kg ha^{-1} on 4 Jan. 2011

Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser (kg ha^{-1})			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
2011/12	PAN 5Q 649 R	24 000	25 Nov. 2011	25 + 76	17	8	Roundup 3 ℓ, Dual 500 mℓ, Karate 70 mℓ ha^{-1}	Roundup 2.5 ℓ ha^{-1} 5 Jan. 2012. Roundup 270 mℓ ha^{-1}, Tronic, Assist	Bulldock for stalk borer 12 Jan. 2012
2012/13	PAN 5Q 649 R	24 000	5 Dec. 2012	13 + 67	8	4	Assist 6,8 ℓ , Cipla 4,5 ℓ, Tronic 50 mℓ ha^{-1}. 13 Nov. 2012. Gramoxone 4 ℓ, Karate 70 mℓ ha^{-1}	Roundup 2 ℓ, Dual Gold 300 mℓ ha^{-1}, Tronic, 2% Assist, 8 Jan. 2013. Grammoxone 3 ℓ ha^{-1}, 30 May 2013	None
2013/14	PAN 5Q 649 RR	27 000	28 Nov. 2013	19 + 56	12.5	6.3	Dual 400 mℓ, Karate 70 mℓ, Gramoxone 4 ℓ ha^{-1}	Roundup Powermax 2 ℓ ha^{-1}, Bladbuff, Assist, 28 Feb. 2014	
2014/15	BG 5685 R	25 000	26 Nov. 2014	46 + 54	23	11.5	Gramoxone 2 ℓ ha^{-1}, Dual 800 mℓ ha^{-1}	6 Jan. 2015, Herbiboost 2%, Mamba 4.5 ℓ ha^{-1}.14 Jan. 2014, Mamba 4.5 ℓ ha^{-1}	

Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser (kg ha^{-1})			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
2015/16	BG 5785 BR	25 000	24 Nov 2015	32 + 83	21	11	Roundup, Grammoxone, Dual Gold	12 Jan 2016 Roundup Powermax 300 mℓ ha^{-1}. 23 Feb + 14 April 2016, Roundup Powermax 300 mℓ ha^{-1}, Assist 300 mℓ ha^{-1}, 2.4D 60 mℓ ha^{-1}.	
2016/17	PAN 6Q-865BR	25 000	16 Nov 2016	32 + 83	21	11	Roundup, Grammoxone, Dual Gold	Jan 2017 Roundup Powermax 300 mℓ ha^{-1}. Feb + April 2017, Roundup Powermax 300 mℓ ha^{-1}, Assist 300 mℓ ha^{-1}, 2.4D 60 mℓ ha^{-1}.	
					Sunflower				
2008/09	PAN 7049	44 000	4 Dec. 2008	35 + 0	8	0	Metolachlor (Dual Gold) @ 50 mℓ ha^{-1}	Hand weeding: 15 Jan 2009	None
2009/10	Agsun 8251	40 000	5 Jan. 2010 (replanted)	17 + 28	11	6	Metolachlor @ 60 mℓ ha^{-1}, Roundup 2 ℓ ha^{-1}, Booster 2%	Pantera 500 mℓ, Touchdown 4 ℓ, Bladbuff 100 mℓ, AMSD4 l ℓ ha^{-1}, Phostoxin, 17 Sep. 2009. 2.4D, Touchdown 4 ℓ, Assist 500 mℓ, Bladbuff ha^{-1}, 6 Nov. 2009. Roundup 1.7 ℓ ha^{-1} + Bladbuff & Ammonium sulfate (Boost), 11 Jan. 2010. Hand weeding: March	None

Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha-1)	Planting date	Fertiliser (kg ha-1)			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
2010/11	PAN 7050	40 000	4 Jan. 2010 (replanted)	27 + 70	18	9	Metolachlor @ 60 mℓ ha-1, Roundup 2 ℓ ha-1, Booster 2%	Manual 2 Des. 2010	
2011/12	PAN 7049	40 000	12 Jan. 2012 (replanted)	37.9	25.3	12.6	Roundup 3 ℓ, Dual 300 mℓ, Assist, Tronic, Karate 70 mℓ ha-1	Manual, 15 Feb.2012. Roundup 2 ℓ, 2.4D 700 mℓ, Assist ha-1, 2 May 2012	
2012/13	PAN 7049	40 000	4 Dec. 2012	13 + 28	9	4	Assist 6,8 ℓ , Cipla 4,5 ℓ, Tronic 50 mℓ ha-1. 13 Nov. 2012. Gramoxone 4 ℓ, karate 70 mℓ ha-1, 6 Dec. 2012	Gramoxone 3 ℓ, Dual 300 mℓ ha-1, Tronic, 2%Assist, 8 Jan. 2013. Grammoxone 3 ℓ ha-1, 30 May 2013	
2013/14	PAN 7095 CL	38 000	28 Nov. 2013	12.5 + 28	8.3	4.2	Dual 400 mℓ, Karate 70 mℓ, Gramoxone 4 ℓ ha-1	Euro Lightning ℓ ha-1, 23 Dec. 2014. Manual, 20 Jan. 2014. Roundup Power Max 2 ℓ ha-1, Bladbuff, Assist, 23 Jun. 2014	
2014/15	PAN 7095 CL	38 000	8 Dec. 2014 (replanted)	16 + 18	8	4	Roundup 3 ℓ ha-1, 24 Dec. 2014, Dual Gold 80 mℓ ha-1, Grammoxone 2 ℓ ha-1 Karate ?	Euro Lightning ℓ ha-1. Manual (surviving weeds} 15 Jan 2015,	Karate
2015/16	PAN 7031 CL	80 000	23 Nov 2015	17	11	6	Roundup, Grammoxone, Dual Gold	23 Feb 2016, Roundup Powermax 300 mℓ ha-1, Assist 300 mℓ ha-1, 2.4D 60 mℓ ha-1.	

Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser (kg ha^{-1})			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
2016/17	PAN 7160CLP	80 000	30 Nov 2016	17	11	6	Roundup, Grammoxone, Dual Gold	Feb 2017, Roundup Powermax 300 mℓ ha^{-1}, Assist 300 mℓ ha^{-1}, 2.4D 60 mℓ ha^{-1}.	
					Legume				
2008/09	LS 6161R (soyabean)	330 000 + *Rhizobium*	4 Dec. 2008	10 + 0	20	9	Metolachlor (Dual Gold) @ 50 mℓ ha^{-1}	Roundup: 2.5 ℓ ha^{-1}, 18 Dec. 2008 & 6 Jan. 2009. Manual 15 Jan. 2009	None
2009/10	Egret (soyabean)	330 000 + *Rhizobium*	5 Jan. 2010 (replanted)	17 + 0	11	6	Metolachlor @ 60 mℓ ha^{-1}, Roundup 2 ℓ ha^{-1}, Booster 2%	Manual March 2010	None
2010/11	Betchuana White (cowpea)	110 000 + *Rhizobium*	19 Nov. 2010	17 + 0	11	6	None	Manual 30 Nov. 2010 &10 Jan. 2011	None
2011/12	Betchuana White (cowpea)	110 000 + *Rhizobium*	25 Nov. 2011	25	17	8	Roundup 3 ℓ, Bateleur 1 ℓ, Karate 70 mℓ ha^{-1}	Manual, 5 Jan. 2012	
2012/13	Betchuana White (cowpea)	110 000 + Rhizobium	4 Dec. 2012	13	9	4.4	Assist 6,8 ℓ , Cipla 4,5 ℓ, Tronic 50 mℓ ha^{-1}. 13 Nov. 2012. Gramoxone 4 ℓ Karate 70 mℓ ha^{-1}, 6 Dec 2012	Gramoxone 3 ℓ, Dual 300 mℓ ha^{-1}, Tronic, 2% Assist, 8 Jan. 2013. Grammoxone 3 ℓ ha^{-1}, 30 May 2013	

Table 10 Agronomy at Buffelsvallei

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser (kg ha^{-1})			Herbicide/Weeding		Pesticide
				N*	P	K	Planting	In season	
2013/14	Betchuana White (cowpea)	129 000 + Rhizobium	28 Nov. 2013	12.5	8.3	4.2	Bateleur l ℓ, Gramoxone 2 ℓ, Karate 70 mℓ ha^{-1}	Euro Lightning l ℓ ha^{-1}, 23 Dec. 2013	
2014/15	Betchuana White (cowpea)	78 000 + Rhizobium	17 Nov. 2014	16	8	4	Bateleur l ℓ ha^{-1}, Karate 70 mℓ, Gramoxone 4 ℓ ha^{-1}	Gramoxone 2.5 ℓ ha^{-1}, 6 Jan. 2015. Manual (surviving weeds} 15 Jan 2015,	Phostoxin, 28 Nov. 2014 & 15 Dec. 2014
2015/16	Betchuana White	100 000	23 Nov 2015	17	11	6	Bateleur l ℓ ha^{-1}.	-	-
2016/17	Betchuana White	100 000	30 Nov 2016	17	11	6	Bateleur l ℓ ha^{-1}.	-	-

				Millet					
2008/09	Millet Common	10 kg ha^{-1} + Concep	4 Dec. 2008	0 + 0	0	0	Roundup 2 ℓ,Dual 500 mℓ ha^{-1}	Manual 15 Jan. 2009	
2009/10	Millet Common	10 kg ha^{-1}	14 Dec. 2009 (replanted)	17 + 0	11	6	None		
2010/11	Millet Common	10 kg ha^{-1}	23 Nov. 2010	27 + 70	18	9	None	Manual 10 Jan. 2011. Roundup mix 2 ℓ ha^{-1}, 10 May 2011	
2011/12	Millet Common	10 kg ha^{-1}	25 Nov. 2011	25 + 76	17	8	Roundup 3 ℓ ha^{-1}, Dual 50 mℓ ha^{-1}	Manual 5 Jan. & 15 Feb. 2012	
2012/13	Millet Common	10 kg ha^{-1}	4 Dec. 2012	13 + 69	8	4.2	Assist 6,8 ℓ, Cipla 4,5 ℓ, Tronic 50 mℓ ha^{-1}. 13 Nov. 2012. Dual 35 mℓ ha^{-1} between rows	Gramoxone 3 ℓ, Dual 300 mℓ $ha^{-1,}$ Tronic, 2% Assist, 8 Jan. 2013. Gramoxone 3 ℓ ha^{-1}, 30 May 2013	
2013/14	Millet Common	10 kg ha^{-1}	28 Nov. 2013	12.5	8.3	4.2	None	Gramoxone 3 ℓ ha^{-1} between rows. 30 Dec. 2013. Manual, 20 Feb. 2014	
2014/15	Millet Okoshana	10 kg ha^{-1}	8 Dec. 2014 (replanted)	16.0 + 27	8.0	4.0	None	Gramoxone 2.5 ℓ ha^{-1}, 9 Jan. 2015. Manual (surviving weeds} 15 Jan 2015	Karate, 25 Nov. 2014
2015/16	Millet Okoshana	10 kg ha^{-1}	23 Nov 2015	32	21	11	Gramoxone 2.5 ℓ ha^{-1}	LAN 83 kg ha^{-1}	
2016/17	Millet Common	10 kg ha^{-1}	30 Nov 2016	32	21	11	Gramoxone 2.5 ℓ ha^{-1}	LAN 83 kg ha^{-1}	

*Rate applied at planting + top dress rate about six weeks after planting.

** Roundup were always mixed with 2% Booster wetting agent and 100 mℓ Bladbuff.

Table 11 Actions taken at Buffelsvallei outside the active growing period

Season	Cultivation	Herbicide applications
2008/09	Rip whole are to depth of 40 cm early Nov. 2008. Rolmoer whole area July 2009. Chisel plough plot of crop system 1 during Aug. 2009.	Quizalofop-p-tefuryl (Pantera) 500 mℓ, Roundup 4 ℓ, (Touchdown), Assist 500 mℓ ha^{-1}, Bladbuff 17 Aug. 2009. Phostoxin, 17 Sep. 2009.
2009/10	Rolmoer crop system 1 during July 2010 and push rest over with tractor.	2.4 D Amine 500 mℓ ha^{-1}, Roundup 4 ℓ ha^{-1}, Quizalofop-P-tefuryl 500 mℓ ha^{-1}, 6 Nov. 2009. Roundup 4 ℓ ha^{-1}, 7 Aug. 2010. Gramoxone 3 ℓ $ha^{-1,}$ Agril 50 mℓ 100 ℓ Roundup 2 ℓ ha^{-1}, 9 Aug. 2010, spots only. Roundup 4 ℓ ha^{-1}, 7 Sept. 2010
2010/11	Chisel plough plot of crop system 1 on 11 Nov. 2010.	
2011/12	Chisel plough all plots of crop system 1, 30 cm deep x 30 cm spacing, 2 Nov. 2011. Rolmoer + Disking 28 Aug. 2012.	Roundup 2 ℓ, 2,4 D 700 mℓ ha^{-1}, 3 May 2012.
2012/13	Disc system 1 plots on 28 Nov 2012.	Roundup 2 ℓ ha^{-1}, 13 Nov 2012 . Gramoxone 4 ℓ ha^{-1}, 30 May 2013. Manual weeding Sep. 2013 - single weeds.
2013/14	Plough conventional trial plots	Roundup Powermax 2 ℓ ha^{-1}, Bladbuff, Assist, 16 Oct. 2014. 1.1 t ha^{-1} dolomitic lime (Vaalbrug) on replication 3 and 4; and reps 1 and 2, 22 Oct. 2014.
2014/15	Plough conventional trial plots Test water infiltration & dig profile holes, 23 Feb. 2015	Phostoxin, 6 Jan. 2015
2015/16	Plough conventional trial plots	Mamba 480SL 2 ℓ ha^{-1}, Bladbuff & Assist 2%, 7 Oct 2015. Disc conventional plots ±7,5 cm, 23 Nov 2015
2016/17	Plough conventional trial plots	Mamba 480SL 2 ℓ ha^{-1}, Bladbuff & Assist 2%, Oct 2016. Disc conventional plots ±7,5 cm, Nov 2016

Table 12 Agronomy at Erfdeel

Season	Cultivar	Plant density (seeds ha^{-1})	Planting date	Fertiliser at planting (kg ha^{-1})			Herbicide/Weeding/Pest control	
				N	P	K	Planting	In season
				Maize				
2008/09	PAN 6Q-521R	28 000	24 Nov. 2008	50 + 0	13	5	Dual Gold, 750 mℓ, Roundup 2 ℓ ha^{-1}	Roundup 2.5 ℓ ha^{-1}, 15 Dec. 2008 & 15 Jan. 2009. Manual, 28 Jan. 2009
2009/10	PAN 6Q-521R	20 000	23 Nov. 2009	16 + 81 + 20	11	6	Dual Gold, 600 mℓ ha^{-1}	Touchdown 4 ℓ, 24D ha^{-1}, 3 Nov. 2009. Roundup 1.7 ℓ, Bladbuff 250 mℓ, Booster 6 ℓ ha^{-1}, 11 Jan. 2010.
2010/11	PAN 6P-563 R	24 500	25 Nov. 2010	27 + 70 + 35.6	18	9	Dual Gold 600 mℓ ha^{-1}	Manual, 6 Dec. 2010. Manual, 19 Jan. 2011. Roundup 300 mℓ, Dual 43 mℓ, Booster 300 mℓ, pH 7,5 mℓ ha^{-1}, 24 Jan. 2011. Roundup 300 mℓ, Dual 43 mℓ, Booster 300 mℓ, pH 7,5 mℓ ha^{-1}, 5 May 2011.
2011/12	PAN 5Q 649 R	24 000	12 Dec 2011	24 + 76	16	8	Dual Gold^{+} 250 mℓ, Roundup 2.8 ℓ ha^{-1}, 2.4 D 500 mℓ, Karate 70 ml ha^{-1}	Manual, 1 March 2012. Cipla 360, Phostoxin 8 May 2012
2012/13	PAN 5Q 649 R	24 000	16 Nov. 2012	25 + 75	17	22	Dual Gold^{+} 300 mℓ, Karate 70 mℓ ha^{-1}	Assist 5,6 ℓ, Springbok 3,3 ℓ, Tronic 50 mℓ ha^{-1}. Manual, 20 Jan. 2013. Manual, 23 Apr. 2013

2013/14	PAN 5Q 649 RR	25 000	25 Nov. 2013	32 + 33.6 + 33.6	16	20	Dual Gold+ 250 mℓ, Karate 70 mℓ ha^{-1}.	Lime & Gypsum 2,5 t ha^{-1}. Turbo Maize 2 ℓ.1% ureum ha^{-1}, 11 Dec 2013. Roundup Power Max 1,8 ℓ, Assist 1,5 ℓ, Tronic 50 mℓ ha^{-1}, 7 Jan 2014. Roundup Power Max 1,8 ℓ, Assist 1,5 ℓ, Tronic 50 mℓ ha^{-1}, 3 Jul. 2014
2014/15	BG 5685 R	22 000		35 + 64	18	9	Dual Gold 720 mℓ, Gramoxone 2 ℓ, Karate 10 mℓ ha^{-1}	Combat, 13 Jan 2015. Mamba 480, 4,5 ℓ, Grammoxone 1,8 ℓ, Herbiboost 2%, 31 Mar. 2015. Mamba 480, 2 ℓ, Assist 2% , Tronic 50 ml ha^{-1}2015/16
2015/16	BG 5785 BR	22 000	30 Nov 2015	28	19	9 +26 KCl	Dual Gold 900 mℓ, Gramoxone 2.6 ℓ, Karate 90 mℓ ha^{-1}	Roundup Powermax 300 ml, Assist 200 ml, 24D 150 ml, 25 Apr 2016.
2016/17	PAN 6Q-865BR	22 000	16 Nov 2016	28	19	9 +26 KCl	Dual Gold 900 mℓ, Gramoxone 2.6 ℓ, Karate 90 mℓ ha^{-1}	Roundup Powermax 300 ml, Assist 200 ml, 24D 150 ml, 25 Apr 2016.
				Sunflower				
2008/09	PAN 7049	44 000	1 Dec. 2008	40 + 0	8	0	Dual Gold 500 mℓ ha^{-1}	Manual, 28 Jan. 2009
2009/10	Agsun 8251	40 000	24 Nov. 2009	11 + 23	11	6	Dual Gold 600 mℓ ha^{-1}	
				Legume				
2008/09	LS 6161R (soyabean)	330 000 + *Rhizobium*	1 Dec. 2008	10 + 0	20	9	Dual Gold 750 mℓ, Roundup 2 ℓ ha^{-1}	Roundup: 2.5 ℓ ha-1, 15 Dec. 2008 & 15 Jan. 2009. Manual, 28 Jan. 2009
2009/10	Egret (soyabean)	330 000 + *Rhizobium*	24 Nov. 2009	11+ 0	11	6	Dual Gold 600 mℓ ha^{-1}	

2010/11	Betchuana Wit (cowpea)	110 000 + *Rhizobium*	25 Nov. 2010	27+ 0	18	9	Manual, 6 Dec. 2010.	None
2011/12	Betchuana Wit	110 000 + *Rhizobium*	12 Dec. 2011	23 + 76	11	6	Bateleur 700 mℓ, Roundup 2.8 ℓ, 2.4 D 500 mℓ, 70 mℓ Karate ha ^{1}	Manual, 1 March 2012. Cipla 360, Phostoxin 8 May 2012
2012/13	Betchuana Wit	110 000 + *Rhizobium*	16 Nov. 2012	12 + 0	8	11	Bateleur 1 ℓ, Karate 70 mℓ ha^{-1}	Manual 20 Jan. 2013.. Manual 23 Apr. 2013
2013/14	Betchuana Wit	129 000 + *Rhizobium*	25 Nov. 2013	16 + 0	8	4	Bateleur 700 mℓ, Karate 70 mℓ ha^{-1}	None
2014/15	Betchuana Wit	78 000 + Rhizobium	17 Nov. 2014	18 + 32	9	4 + 12	Bateleur 2 ℓ, Gramoxone 2 ℓ ha^{-1}	Gramoxone 1.8 ℓ ha^{-1} between rows
2015/16	Betchuana Wit	78 000 + Rhizobium	30 Nov 2015	15	10	5 +14 KCl	Bateleur 700 mℓ, Karate 70 mℓ ha^{-1}	Gramoxone 1.8 ℓ ha^{-1} between rows
2016/17	Betchuana Wit	78 000 + Rhizobium	30 Nov 2015	15	10	5 +14 KCl	Bateleur 700 mℓ, Karate 70 mℓ ha^{-1}	Gramoxone 1.8 ℓ ha^{-1} between rows
				Millet				
2008/09	Common	10 kg ha^{-1}	2 Dec. 2008	40	0	0		Roundup 15 Dec. 2008. Grammoxone, Roundup 17 Dec. 2008
2009/10	Common	10 kg ha^{-1}	5 Jan. 2010 (replanted)	17 + 20	11	6	None	
2010/11	Common	10 kg ha^{-1}	20 Dec. 2010 (replanted)	27 + 70	18	9	Roundup 1.7 ℓ ha^{-}1, Bladbuff, Ammonium sulfate (Boost), 20 Dec 2010	Manual, 20 Dec. 2010. Roundup 2 ℓ ha^{-1} 5 May 2011

2011/12	Common	10 kg ha^{-1}	12 Dec. 2011	23 + 76	11	6	Dual Gold+ 250 mℓ, Roundup 2.8 ℓ ha^{-1}, 2.4 D 500 mℓ, Karate 70 ml ha^{-1} between rows	Manual, 1 March 2012. Cipla 360, Phostoxin 8 May 2012
2012/13	Common	10 kg ha^{-1}	16 Nov 2012. 10 Dec. 2012 (replanted)	12 replant, 28 + 30	8	11	Dual Gold+ 300 mℓ, Karate 70mℓ ha^{-1} between rows	Lay frost cover, 20 Nov. 2012. Manual 20 Jan. 2013. Manual 23 Apr. 2013
2013/14	Common	10 kg ha^{-1}	25 Nov. 2013	16 + 50	8	4	None	Turbo Maize 2 ℓ, Ureum 1% ha^{-1} 11 Dec. 2013. Lay frost cover, 26 Nov. 2013. Turbo Maize 2 ℓ, Ureum 1% ha^{-1}, 7 Jan. 2014
2014/15	Okashana 1	10 kg ha^{-1}	28 Nov. 2014 (replanted)	18 + 23	9	4 + 12	None	28 Nov. 2014, Phostoxin, 13 Jan. 2015. Grammoxone 1.8 ℓ ha^{-1}
2015/16	Okashana 1	10 kg ha^{-1}	30 Nov 2015	28	19	9 +26 KCl	Grammoxone 1,7 l ha^{-1}	Roundup Powermax 300 ml, Assist 200 ml, 24D 150 ml, 25 Apr 2016.

Table 13 Actions taken at Erfdeel outside the active growing period

Season	Cultivation	Herbicide applications and other actions
2008/09	Rip whole area to depth of 40 cm 17 Nov. 2008. Rolmoer whole area July 2009	Apply 2 ton ha^{-1} 60% lime & 40% gypsum mixture (Greentop 40) and disk in.
2009/10	Rip conventional system plots (crop system 1) during Aug. 2009.	2.4 D Amine 500 mℓ ha^{-1}, Roundup 4 ℓ ha^{-1}, Quizalofop-P-tefuryl 500 mℓ ha^{-1}, 3 Nov. 2009, before planting
2010/11	Mouldboard plough 25 cm deep on 23 Aug. 2010.	Dolomitic lime 4.2 t, Gypsum 2.5 t ha^{-1}, 19 Aug., 2010.

2011/12	Rip 40 cm deep 14 Sept. 2011; Crop system T1 - chisel plough 30 cm deep.	Roundup 300 mℓ, Dual 43 mℓ, Booster 300 mℓ, pH 7,5 mℓ ha^{-1}, 3-5 Aug. 2011 on spots only. Lime and gypsum applied on selected plots on 11 Nov. 2011. Roundup 2 ℓ ha^{-1}, 8-9 May 2012 on all plots.
2012/13	Rolmoer & Rip 60 cm deep 19 Sept. 2012 ; Crop system T1 only. Rolmoer before planting all other maize plots on 16 Nov. 2012.	Gramoxone 4 ℓ ha^{-1}, June 2013 whole area.
2013/14	Rip conventional system plots with 3 tines. Rolmoer all plots. 24 Oct 2013.	Manual weeding volunteers, Aug. 2013, 2.5 t lime & gypsum and 24 Oct. 2013, 2.5 t ha^{-1} again on plots with high acid saturation. 3 Jul. 2014, Roundup Powermax 2 ℓ ha^{-1}, Bladbuff, Assist. 31 Jul. 2014, manual weeding & Phostoxin.
2014/15	Rolmoer babala x 2, Rip on row, plots 32, 36, 49, 50, 27 Oct. 2014	9 Oct. 2014: Lime & gypsum, plots 29 (1.5 +1.5 t ha^{-1}); 34 (1+1 t ha^{-1}); 35 (2.5+2.5 t ha^{-1}); 42 (2 + 2 t ha^{-1}); 43 (3 + 3 t ha ^{1}); 44 (1 + 1 t ha^{-1}); 45 (1 + 1 t ha^{-1}); 46 (3 + 3 t ha^{-1}). Gramoxone 2 ℓ ha^{-1}.
2015/16	Chisel plough & rip 65 cm with 3 tines on selected plots.	22 Sept 2015: Lime & gypsum, plots: 35 (2.5 t ha^{-1}), 41 (579 kg ha^{-1}), 42 (1.25 t ha^{-1}), 43 (2.9 t ha^{-1}). 20 Oct 2015, Bladbuff-Assist, 24D, Mamba.
2016/17	Chisel plough & rip 65 cm with 3 tines on selected plots.	Oct 2016, Bladbuff-Assist, 24D, Mamba.