WATER HARVESTING FOR DRYLAND FARMING

. . . . Mini-catchment Runoff Farming (IRWH)

. . . . Flood-Runoff Farming (FRF)

Weldemichael A. Tesfuhuney, S. Walker & LD. van Rensburg

Department of Soil, Crop & Climate Sciences

T: 051 401 9111 info@ufs.ac.za **www.ufs.ac.za**

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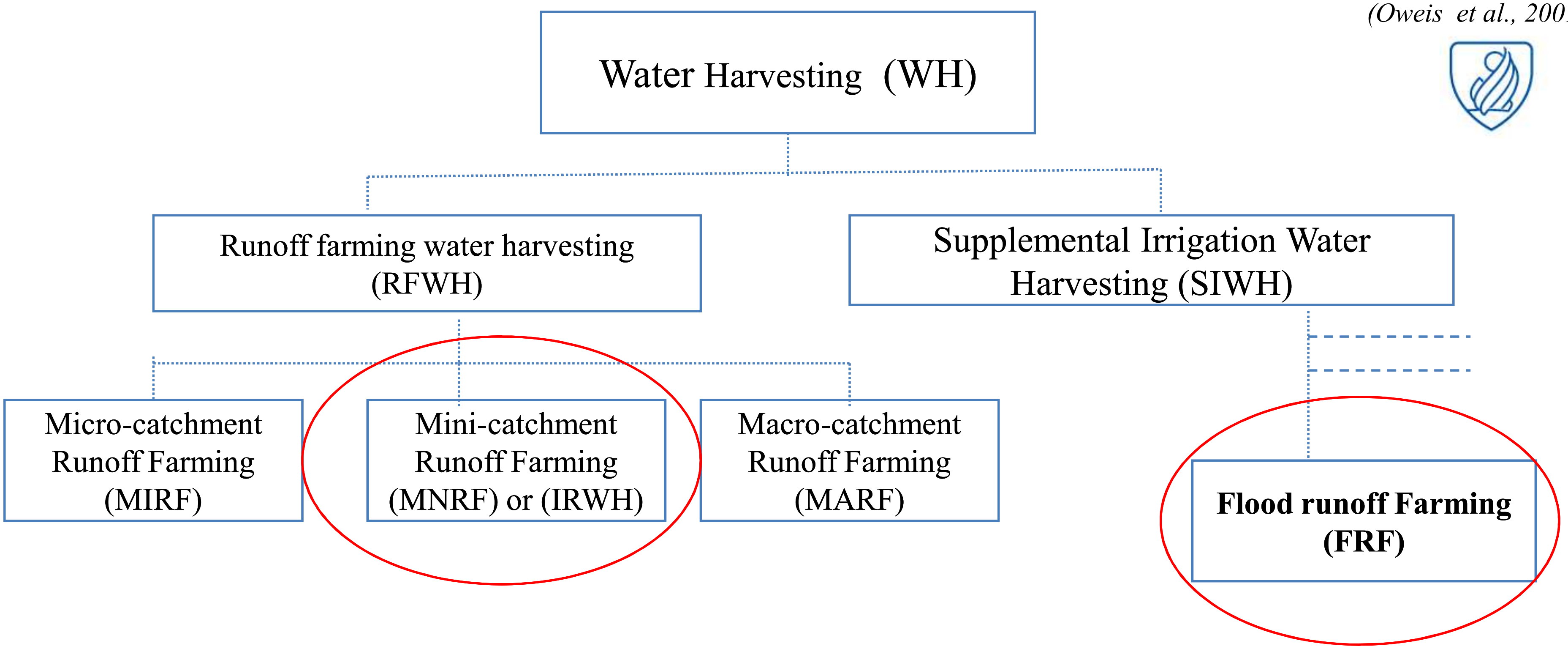
NATURAL AND AGRICULTURAL SCIENCES
NATUUR- EN LANDBOUWETENSKAPPE

(Oweis et al., 2001)



Common feature:

- collection of water for its productive use
- minimize unproductive water in water scarce area
- spatial intervention designed to change allocation of water to balance ET of crops

Differences:

- scale, system, approach, resources, application

Major challenge:

- insufficient soil water requirement particularly during sensitive growth stages
- to rely on an alternative manageable conservation techniques

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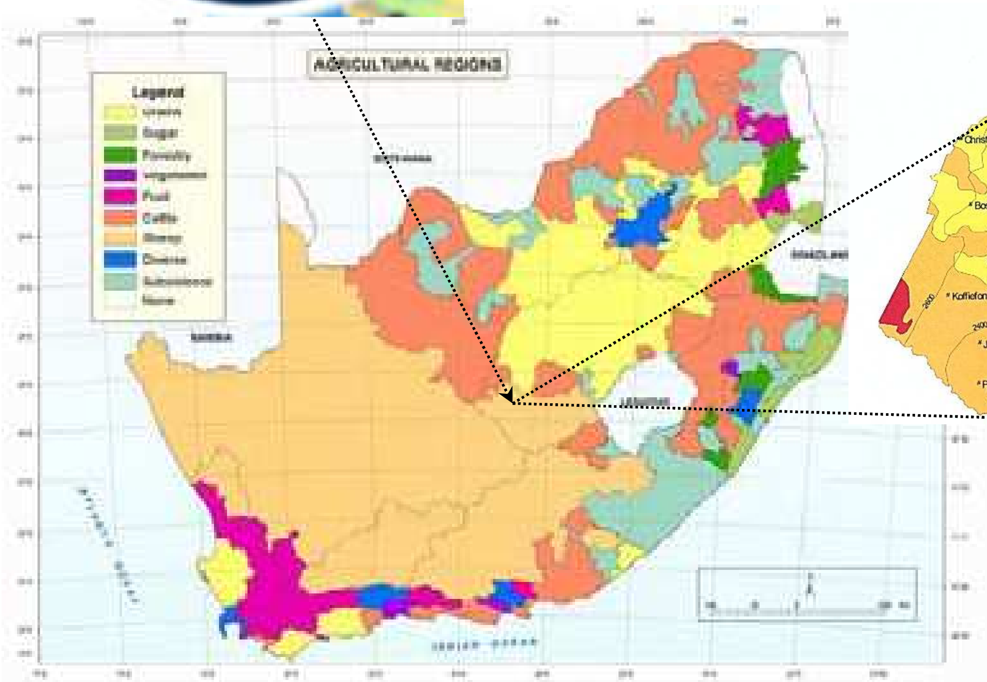
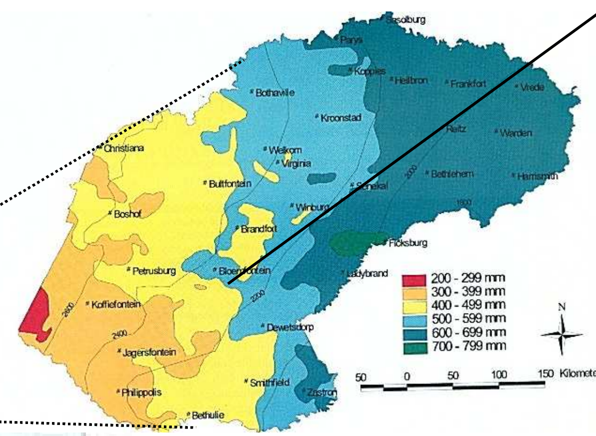
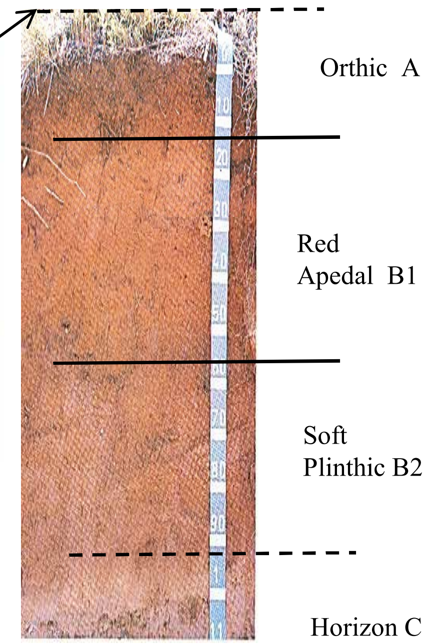
In-field Runoff as Affected by Surface Treatments & to Compute Water Balance & Productivity for Maize Production

Ecotope

- ◊ Climate — Semi-arid area
- ◊ Soil — Fine sandy loam
- ◊ Topography — 1%







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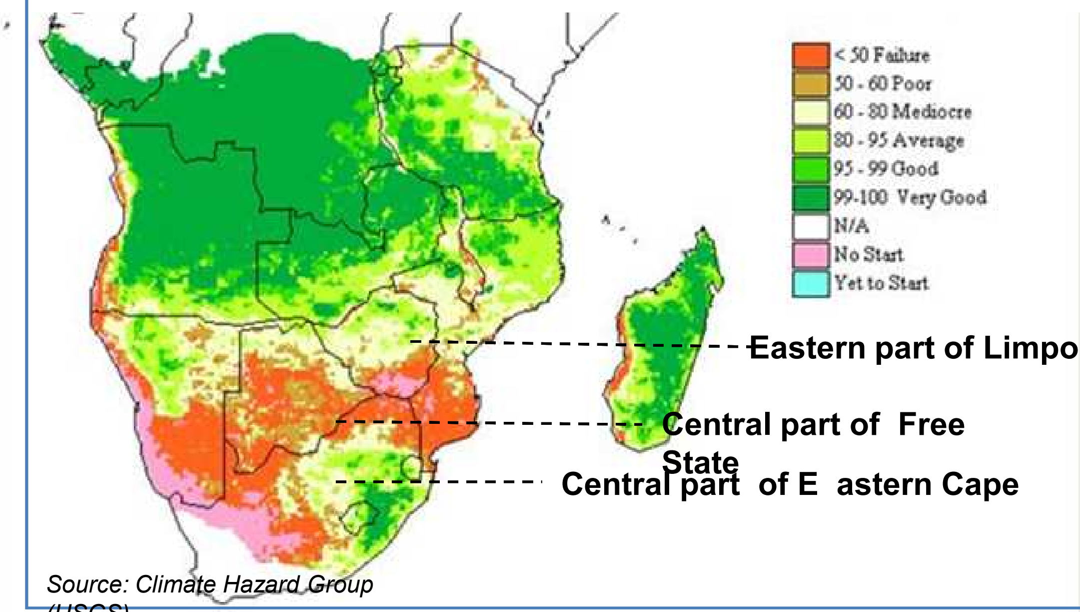
Over view of Mini-catchment Runoff Farming (IRWH)

- an age old practice used in water scarce rainfed crop production areas
- "the process of concentrating precipitation through runoff and storing it for beneficial use" (Hensley, 2000)
- in semi-arid areas can easily double PUE, thus contributing to food security (Stroosnijder 2003)
- Innovative interventions of the technique of RWH has been developed (over 16 years) (Central Free State, Central Eastern cape & Easter part of Limpopo; 42, 19, 8 rural communities)



Source: Climate Hazard Group (USGS)

- However, widespread understanding and diversified knowledge of IRWH has not yet been comprehensively appraised.

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Over all aim

To evaluate unproductive water losses from various surface treatments and compute soil water balance for IRWH

Objectives:

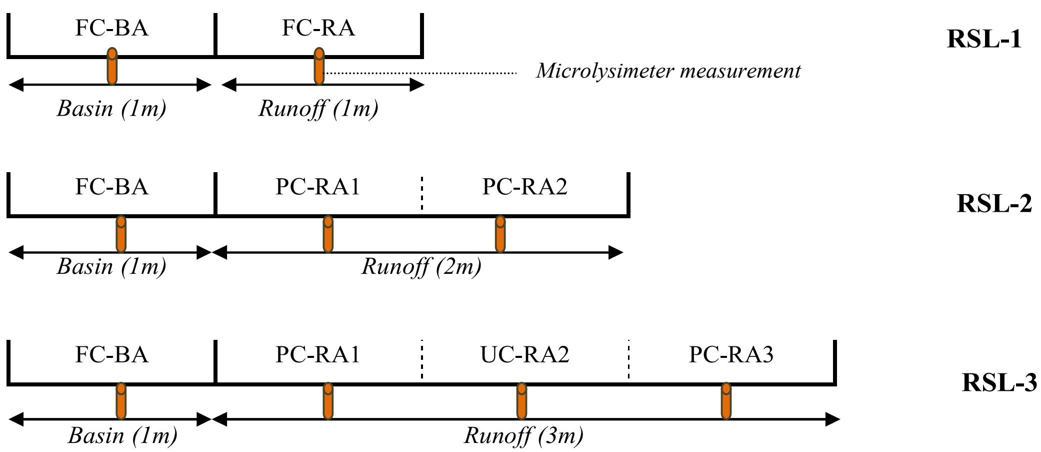
- to quantify the effect of surface properties and to derive a simple empirical model to predict in-field runoff

- to develop empirical models to estimate cumulative soil evaporation across the basin and runoff sections as influenced ***"dry-mulch" & "green-mulch"***

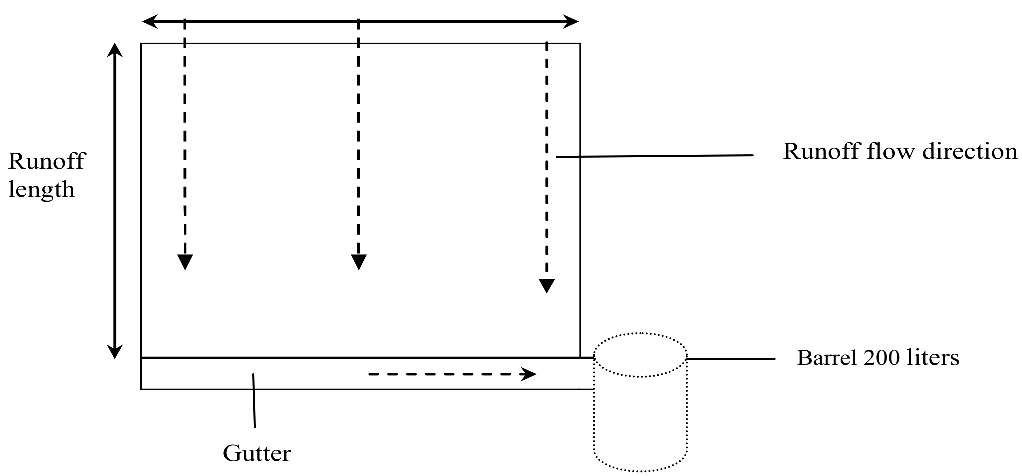
Measurements

Layout:

- Runoff length strips , RSL (1, 2, 3 m)
- Mulching level, ML (bare – 5 t ha^{-1})

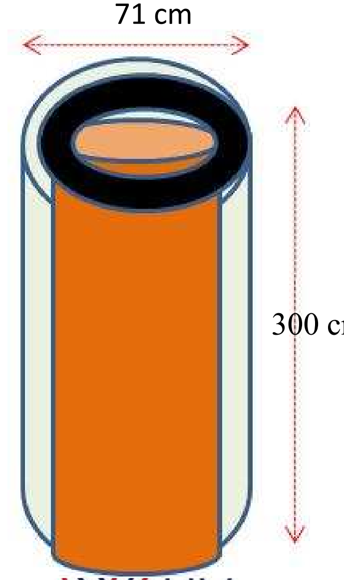


Runoff measurement frame



Neutron Probe

Microlysimeter



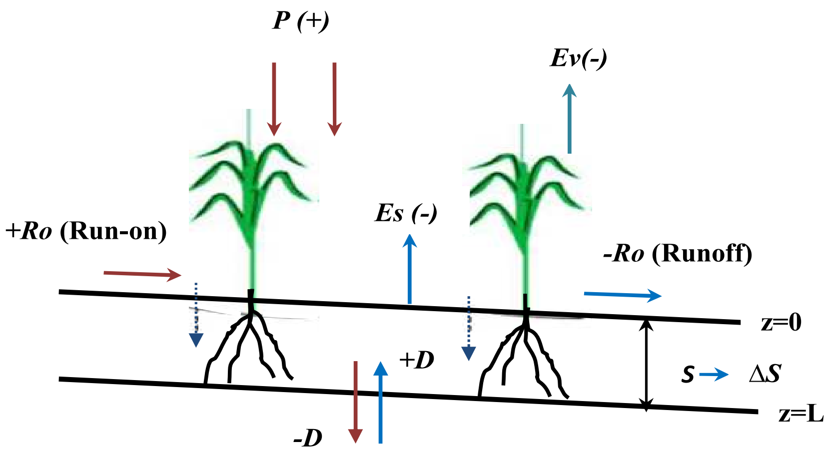
Water Balance

Water for yield = water gain – water losses

$$Ev = (P \pm \Delta S) - (Ro + Es + D)$$

- *Runoff area (RA):* $Ev = P - R_{off} - Es - D \pm \Delta S$
- *Basin area (BA):* $Ev = P + R_{on} - RCI - Es - D \pm \Delta S$

$$RCI = S_{max} \times \left[1 - e^{-(1-p_l)\frac{RF_{event}}{S_{max}}}\right]$$ *.... Rainfall canopy interception*



In-field runoff (Ro)

- as a function of RF characteristics & surface treatment.

Soil Evaporation (Es)

- from each 1 m section, Stroosnijder model

Evaluated as:

- ***Unproductive water (± Ro, Es, D)***
- ***Productive water for yield (SW, Ev), WUE=Y/ET, WP=Y/Ev) (Kg ha^{-1} mm^{-1})***

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Results

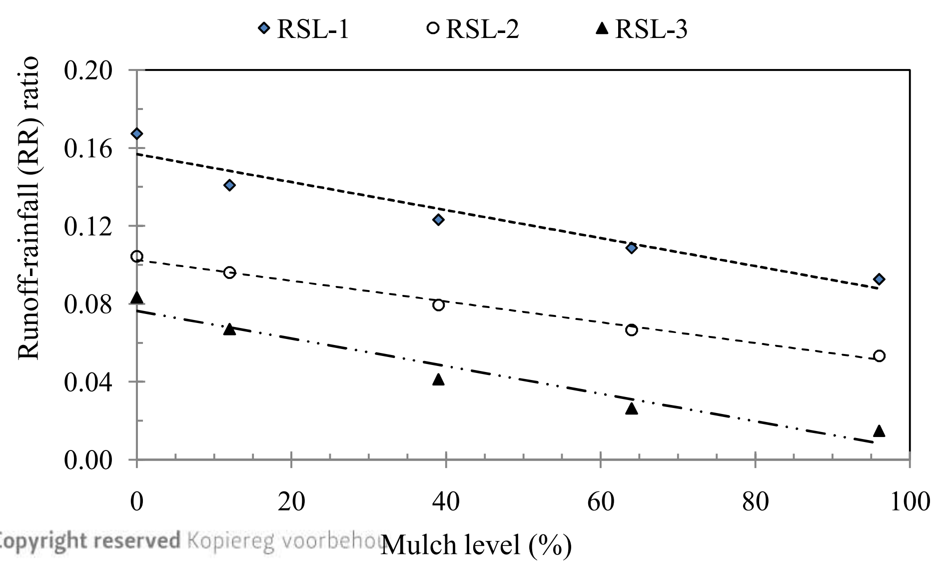
Rainfall Characteristics

Event amount: Class range (mm)	%	Event duration: Class range (min)	%	Event peak intensity: Class range (mm h^{-1})	%
x ≤ 1	**23.1**	1 < x ≤ 60	**44.1**	x ≤ 10	**71.2**
1 < x ≤ 8	**61.0**	60 < x ≤ 120	**9.6**	10 < x ≤ 25	**15.4**
8 < x ≤ 15	**11.5**	120 < x ≤ 180	**26.9**	25 < x ≤ 50	**13.5**
15 < x ≤ 20	**1.9**	180 < x ≤ 240	7.7	50 < x ≤ 75	**-**
20 < x ≤ 30	**1,9**	x > 240	**9.5**	75 < x ≤ 100	**-**

In-field Runoff Ratio

Runoff strip length (RSL)	Mulch level (ML as %) 0%	39%	96%
1 m	27	16	17
2 m	21	10	8
3 m	15	6	4

Relationships with Surface Treatments



RSL-1: $y = -0.072x + 0.156$, $R^2 = 0.93$

RSL-2: $y = -0.053x + 0.104$, $R^2 = 0.99$

RSL-3: $y = -0.071x + 0.076$, $R^2 = 0.94$

- **Slopes show insignificant**
- **Intercept s are significant differences**

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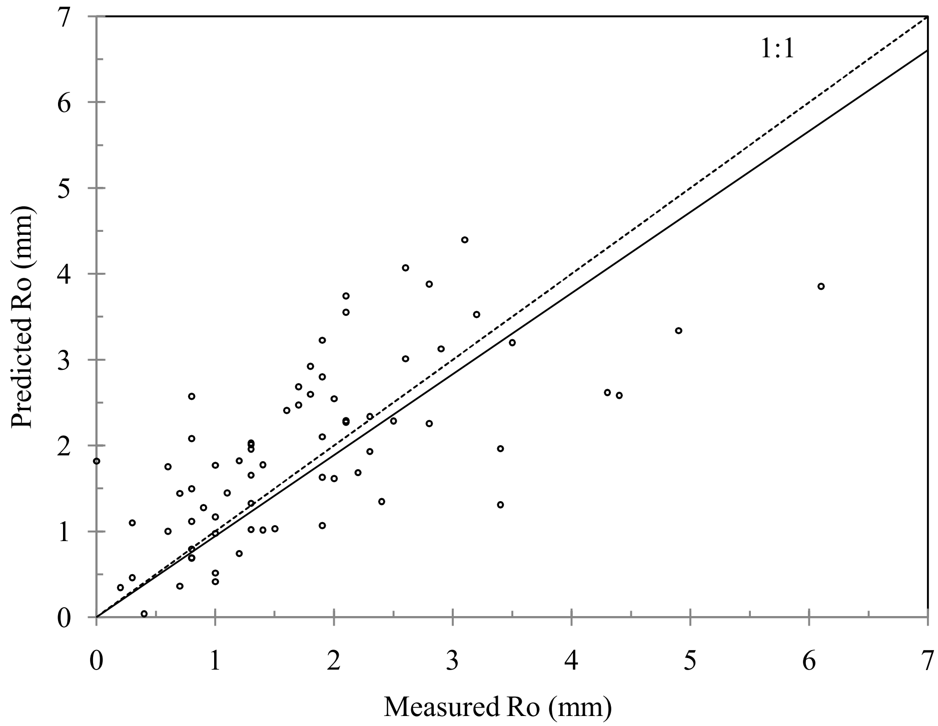
Predicting runoff as function of RF charactertics & Surface treatments

- Linear regression models were used for prediction and evaluation of the effects of the different parameters
- Stepwise regression analysis produced multiple linear regression model

$$Ro = 1.023 + 0.138RF + 0.033Pi - 0.654RSL - 0.013ML$$

- RF = Rainfall amount during rain event (mm),
- Pi = Peak rainfall intensity (mm h^{-1}).
- ML = Mulch level (%)
- RSL = Runoff strip length (m)

Model Verification



n	**71**
RMSE	**0.89**
RMSEs	**0.45**
RMSEu	**0.77**
MAE	**0.71**
R^2	**0.48**
D-index	**0.97**
slope (b)	**0.63**
intercept (a)	**0.79**
RMSEs/RMSE	**0.51**

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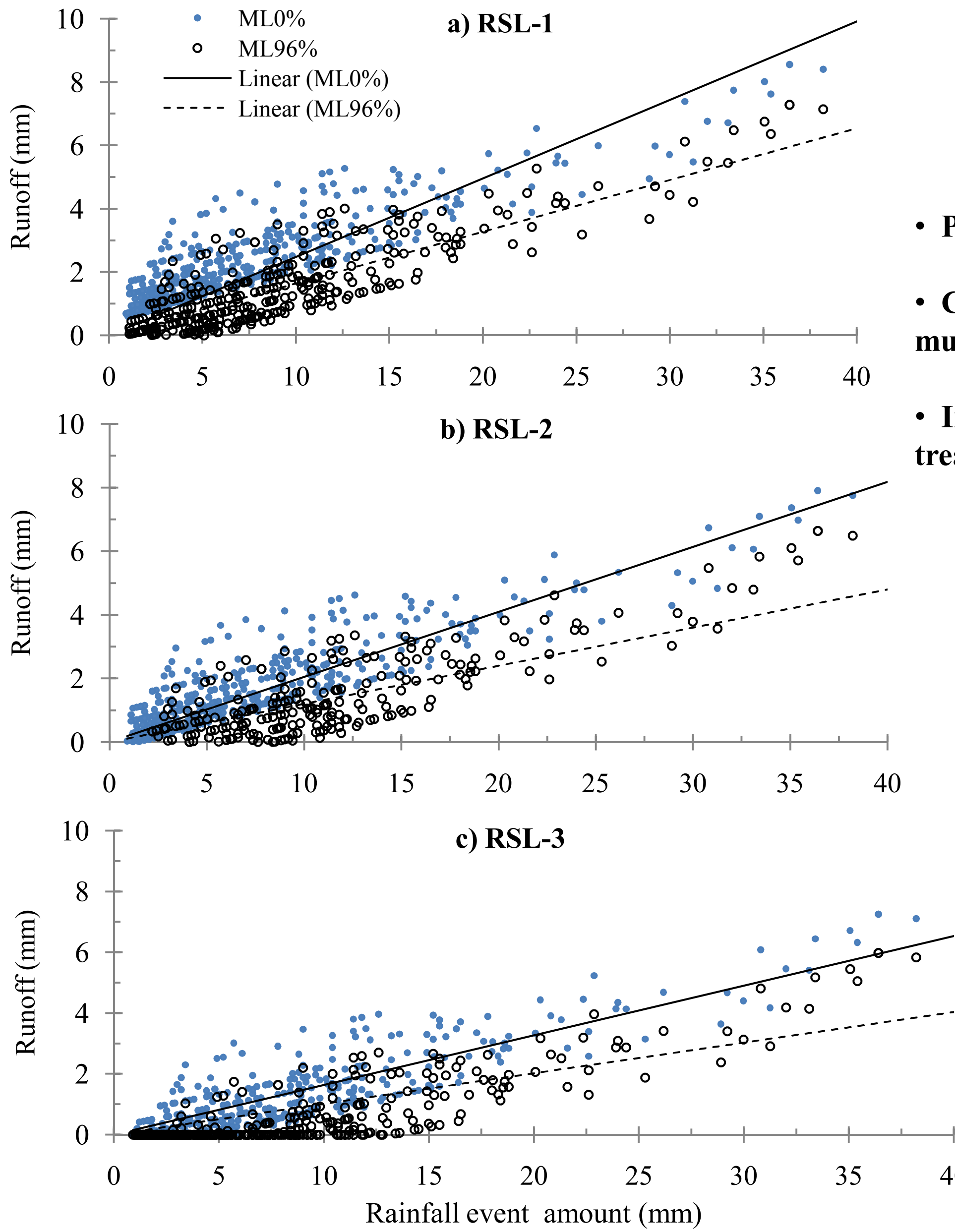
Long-term in-field runoff predictions



- Predicted Ro steeper in Bare compared to mulched
- Concentration of Ro=0 increased with increase length & mulch cover
- Implies, importance of small rains on various surface treatments

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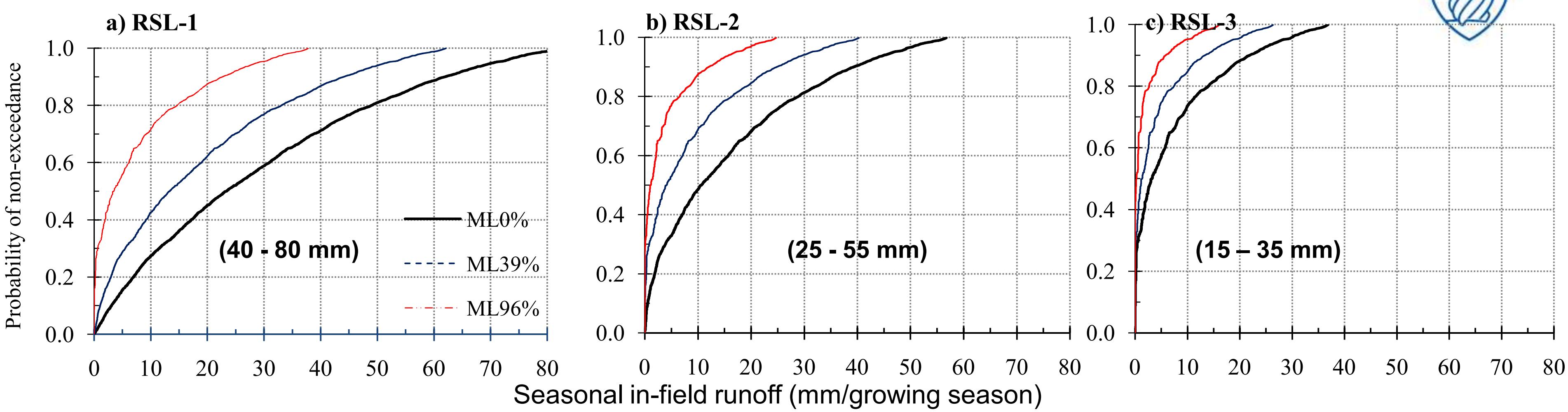
Probability Curves for in-field runoff predictions during maize growing season



- **80% probability = to harvest 48, 28 & 14 mm from RSL-1, 2 & 3**
- **40% probability the predicted Ro from wide mulched is insignificant but infiltrated in runoff strips**

Main findings

- Decreasing in runoff from the addition of mulch depends on the length of runoff strip (highest 27% & lowest 4%)

- Bare plots can contribute the highest additional rainwater to the basin area, and that wide fully mulch plots infiltrate
  more rainwater on the runoff area.

- Ability of the soil profile to hold rainwater following a wet period & to be accessed by the roots during short dry spells.

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Soil Evaporation (Es)

- For the estimation of ∑Es) during the crop growing period, **the potential evaporation, leaf area induced canopy shading effect, mulching levels and soil characteristic parameter** were considered.

- Soil surface area shaded by the canopy was computed as a function of BLAR (LAI),

- Canopy structure plays a significant role for improved solar radiation interception

- The combined effect of surface treatments (mulch and shading cover) in reducing the ∑Es were used for different positions in basin and across the runoff section.

Basin area: $\sum Es = -0.1357CS + 19.564$

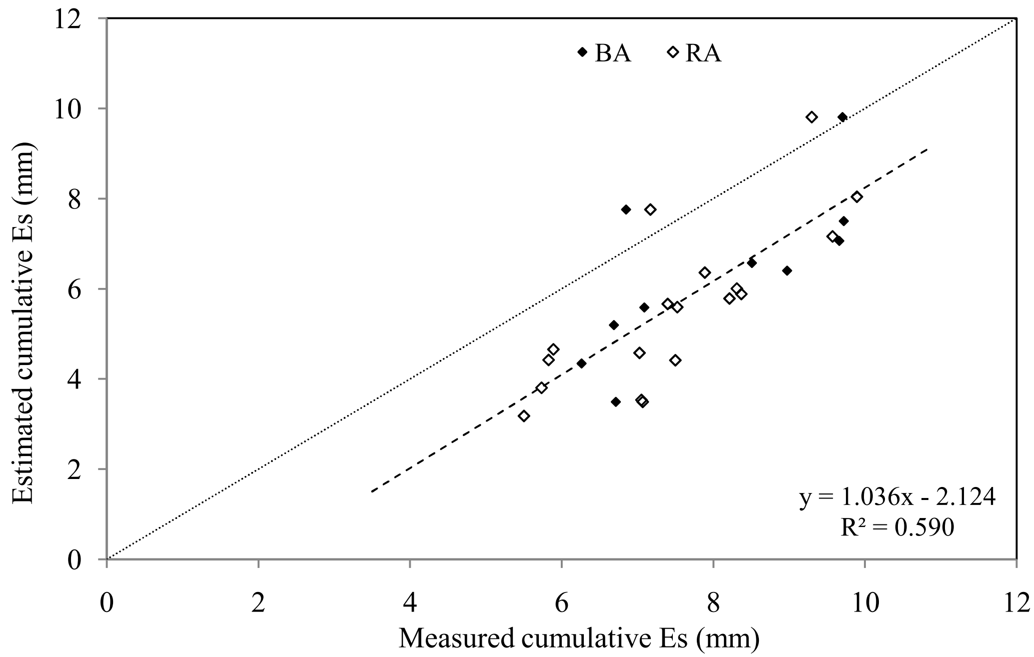
Runoff area: $\sum Es = -0.0912ML - 0.0117CS + 17.163$

$$\sum Es = K_{cover} \beta' \times \sqrt{\sum E_{pot}}$$

- **Values of coefficients factor (K_{cover}) for canopy shading for basin area and mulch cover together with shading effect for runoff area, as calculated from the ratio ∑Es/∑E_{max} and as function of CS% and ML%.**

Mulch or canopy shade cover	Bare	12%	39%	62%	79.5%	96%
Basin Area K_{cover}			0.92	0.56	0.33	
Runoff area K_{cover}						
FC	0.94	0.88	0.73	0.60		0.43
PC	0.97	0.91	0.76	0.63		0.46
UC	1.00	0.94	0.79	0.66		0.49

Evaluations of the measured versus estimated of cumulative soil evaporation



n	**28**
RMSE	**2.164**
MAE	**1.992**
R^2	**0.59**
D-index	**0.64**
RMSEu/RMSE	**0.52**

- **Poor scattered, underestimated of about 24%**
- **Relatively Higher RMSE & MAE**

} Complicated effects of shading & mulch

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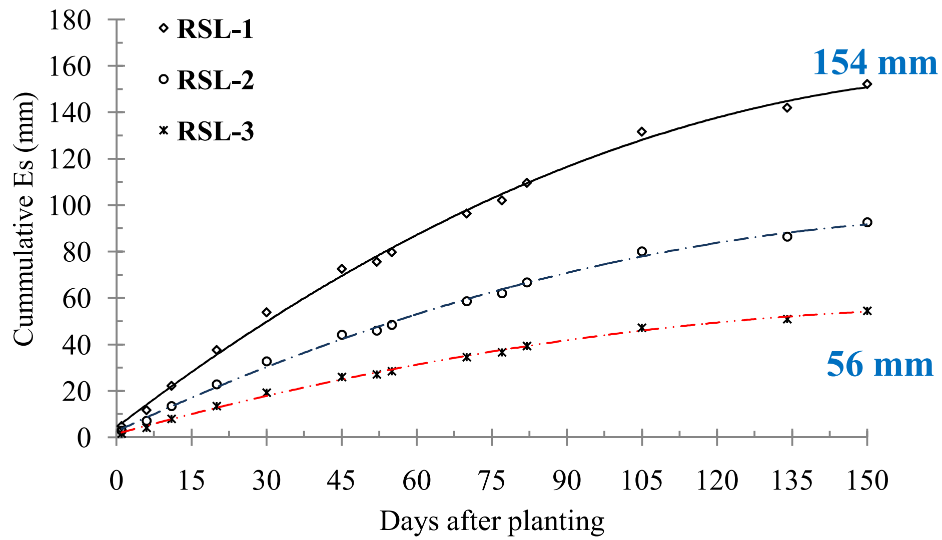
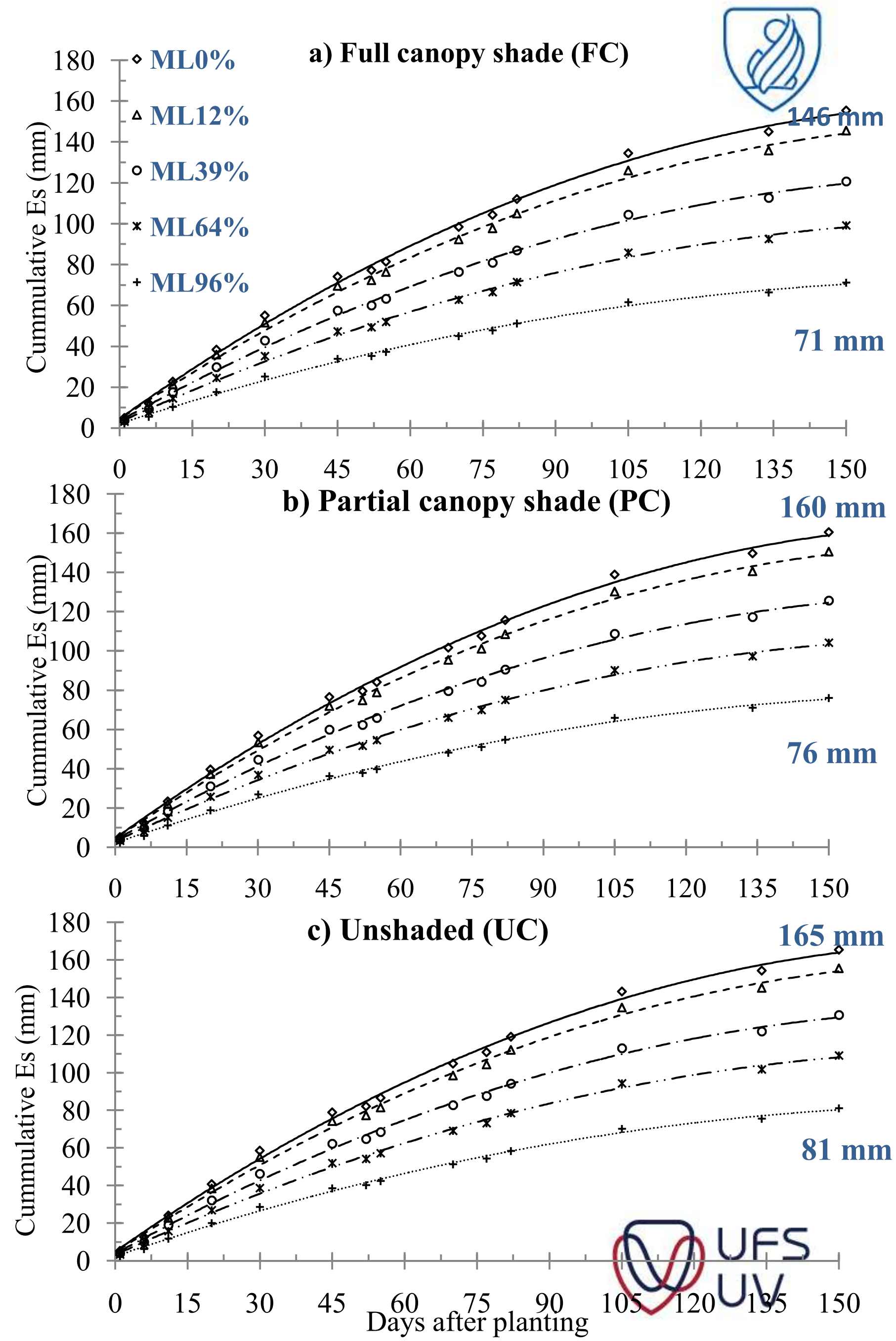
Estimation of Es during the growth period

Basin Area (BA)



Runoff Area (RA)



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e.g. Water Balance Sheet for each 1 m section of IRWH

RSL-3		BA					RA1					RA2					RA3				
ML		0%	12%	39%	64%	96%	0%	12%	39%	64%	96%	0%	12%	39%	64%	96%	0%	12%	39%	64%	96%
P (mm)	GS-I	114.5					114.5					114.5					114.5				
	GS-II	64.6					64.6					64.6					64.6				
	GS-III	30.9					30.9					30.9					30.9				
	GS-IV	39.8					39.8					39.8					39.8				
	GP	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8	249.8
Ro (mm)	GS-I	34.8	31.7	25.8	21.9	19.0	-34.8	-31.7	-25.8	-21.9	-19.0	-34.8	-31.7	-25.8	-21.9	-19.0	-34.8	-31.7	-25.8	-21.9	-19.0
	GS-II	19.7	17.9	14.6	12.4	10.7	-19.7	-17.9	-14.6	-12.4	-10.7	-19.7	-17.9	-14.6	-12.4	-10.7	-19.7	-17.9	-14.6	-12.4	-10.7
	GS-III	9.4	8.6	7.0	5.9	5.1	-9.4	-8.6	-7.0	-5.9	-5.1	-9.4	-8.6	-7.0	-5.9	-5.1	-9.4	-8.6	-7.0	-5.9	-5.1
	GS-IV	12.1	11.0	9.0	7.6	6.6	-12.1	-11.0	-9.0	-7.6	-6.6	-12.1	-11.0	-9.0	-7.6	-6.6	-12.1	-11.0	-9.0	-7.6	-6.6
	GP	76.0	69.2	56.4	47.9	41.5	-76.0	-69.2	-56.4	-47.9	-41.5	-76.0	-69.2	-56.4	-47.9	-41.5	-76.0	-69.2	-56.4	-47.9	-41.5
RCI (mm)	GS-I	0.50	0.50	0.50	0.50	0.50	0.25	0.25	0.25	0.25	0.25						0.25	0.25	0.25	0.25	0.25
	GS-II	2.92	2.92	2.92	2.92	2.92	1.46	1.46	1.46	1.46	1.46						1.46	1.46	1.46	1.46	1.46
	GS-III	2.49	2.49	2.49	2.49	2.49	1.25	1.25	1.25	1.25	1.25						1.25	1.25	1.25	1.25	1.25
	GS-IV	1.79	1.79	1.79	1.79	1.79	0.90	0.90	0.90	0.90	0.90						0.90	0.90	0.90	0.90	0.90
	GP	7.70	7.70	7.70	7.70	7.70	3.85	3.85	3.85	3.85	3.85						3.85	3.85	3.85	3.85	3.85
ΔS (mm)	GS-I	-35.1	-44.5	-4.1	5.2	1.0	-64.7	-41.1	-9.1	-20.9	-13.7	-5.4	-19.8	17.1	-22.4	-5.2	-21.4	-4.7	-30.6	-17.7	-6.8
	GS-II	-22.0	-27.5	-29.5	-15.8	98.4	8.6	38.6	1.6	21.8	16.4	0.3	20.9	-21.5	37.2	11.0	36.1	37.3	15.5	45.5	25.4
	GS-III	-6.0	7.0	22.3	4.5	26.3	66.5	31.1	47.1	9.2	46.7	66.7	30.8	53.2	-27.1	20.1	82.8	45.4	51.1	-16.8	35.1
	GS-IV	-30.0	32.3	98.8	27.2	-0.4	7.8	4.3	9.1	-8.6	-5.3	0.2	10.3	5.9	-9.0	6.6	3.3	0.6	25.9	-10.6	-0.1
	GP	-93.1	-32.7	87.4	21.1	125.3	18.2	32.9	48.7	1.6	44.1	61.8	42.2	54.8	-21.2	32.5	100.8	78.6	61.9	0.4	53.5
D		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
ET Resd. (mm)	GS-I	113.7	101.1	135.7	141.1	133.9	76.5	71.8	79.4	71.5	81.6	78.9	74.1	105.8	70.2	90.3	76.5	77.9	59.9	74.6	88.5
	GS-II	59.4	52.1	46.8	58.3	170.9	52.0	83.8	50.1	72.6	68.8	45.2	67.6	28.4	89.4	64.9	79.5	82.5	64.0	96.2	77.8
	GS-III	31.8	44.0	57.7	38.8	59.8	86.7	52.1	69.7	33.0	71.2	88.2	53.2	77.1	25.3	45.8	103.1	66.5	73.8	24.2	59.6
	GS-IV	20.1	81.4	145.8	72.8	44.2	34.6	32.2	39.0	22.6	27.0	27.8	39.0	36.7	23.2	39.8	30.0	28.4	55.8	20.6	32.1
	GP	225.0	278.6	386.0	311.1	408.8	249.9	239.9	238.2	199.7	248.6	240.1	233.9	248.1	208.1	240.9	289.2	255.4	253.6	215.7	258.0
Es (mm)	GS-I	26.0	26.0	26.0	26.0	26.0	76.5	71.8	59.9	49.7	36.3	78.87	74.14	62.31	52.06	38.65	76.5	71.8	59.9	49.7	36.3
	GS-II	8.5	8.5	8.5	8.5	8.5	25.1	23.6	19.7	16.3	11.9	25.88	24.33	20.44	17.08	12.68	25.1	23.6	19.7	16.3	11.9
	GS-III	12.7	12.7	12.7	12.7	12.7	37.2	34.9	29.1	24.2	17.6	38.35	36.05	30.30	25.31	18.79	37.2	34.9	29.1	24.2	17.6
	GS-IV	7.4	7.4	7.4	7.4	7.4	21.6	20.3	16.9	14.0	10.3	22.29	20.96	17.61	14.71	10.92	21.6	20.3	16.9	14.0	10.3
	GP	54.6	54.6	54.6	54.6	54.6	160.4	150.5	125.7	104.2	76.1	165.4	155.5	130.7	109.2	81.0	160.4	150.5	125.7	104.2	76.1
Ev Resd. (mm)	GS-I	87.7	75.1	109.6	115.1	107.9	0.0	0.0	19.4	21.8	45.3	0.0	0.0	43.5	18.2	51.7	0.0	6.1	0.0	24.9	52.2
	GS-II	50.8	43.6	38.3	49.8	162.3	26.9	60.2	30.5	56.3	56.9	19.4	43.2	8.0	72.4	52.2	54.4	59.0	44.4	79.9	65.8
	GS-III	19.2	31.3	45.0	26.2	47.2	49.5	17.2	40.6	8.8	53.5	49.8	17.1	46.8	0.0	27.0	65.9	31.6	44.6	0.0	42.0
	GS-IV	12.8	74.0	138.4	65.5	36.9	13.0	11.9	22.1	8.6	16.7	5.5	18.1	19.1	8.4	28.9	8.4	8.2	38.9	6.6	21.9
	GP	170.5	224.0	331.4	256.5	354.3	89.5	89.4	112.5	95.5	172.5	74.7	78.4	117.5	99.0	159.8	128.7	104.9	127.8	111.5	181.9

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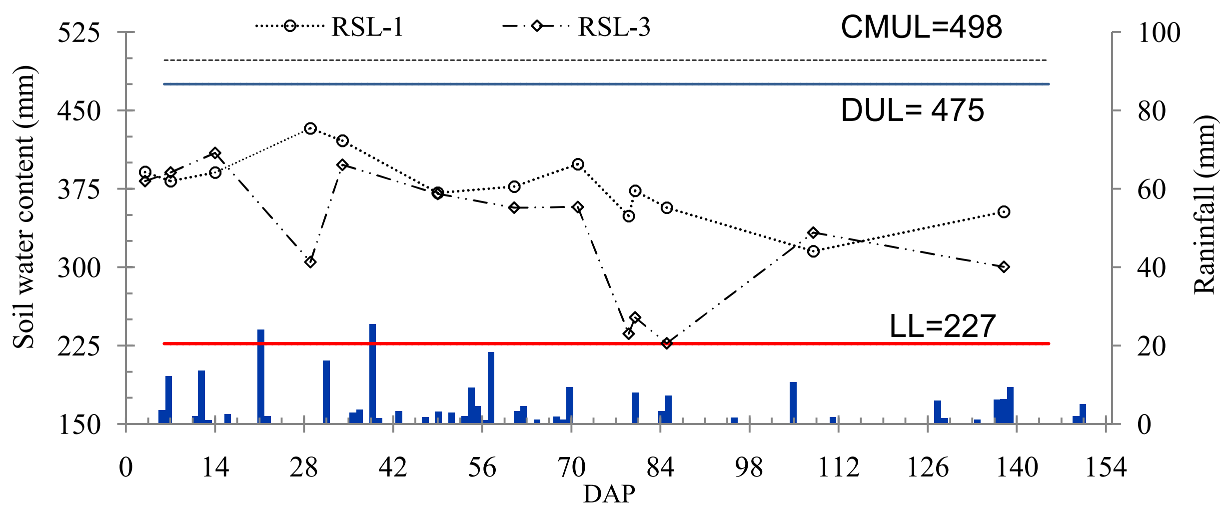
Change in Soil water (ΔS)



Water Balance , Efficiency & Productivity (WUE & WP)

RSL	ML	P (mm)	Ro (%)	Es (mm)	Ev (mm)	S (mm)	Y (kg ha^{-1})	AGDM (kg ha^{-1})	WUE (kg ha^{-1} mm^{-1})	WP (kg ha^{-1} mm^{-1})
Narrow (1 m)	0% (bare)	248.9	27	153.8	149.2	41.6	3277	7147	10.8	22.0
	96% mulched		15	135.2	115.8	57.2	3051	6580	12.2	26.3
Wide (3 m)	0% (bare)	248.9	17	111.6	191.3	33.8	3157	6794	10.4	16.5
	96% mulch ed		4	71.9	217.1	63.9	2666	5668	9.2	12.3

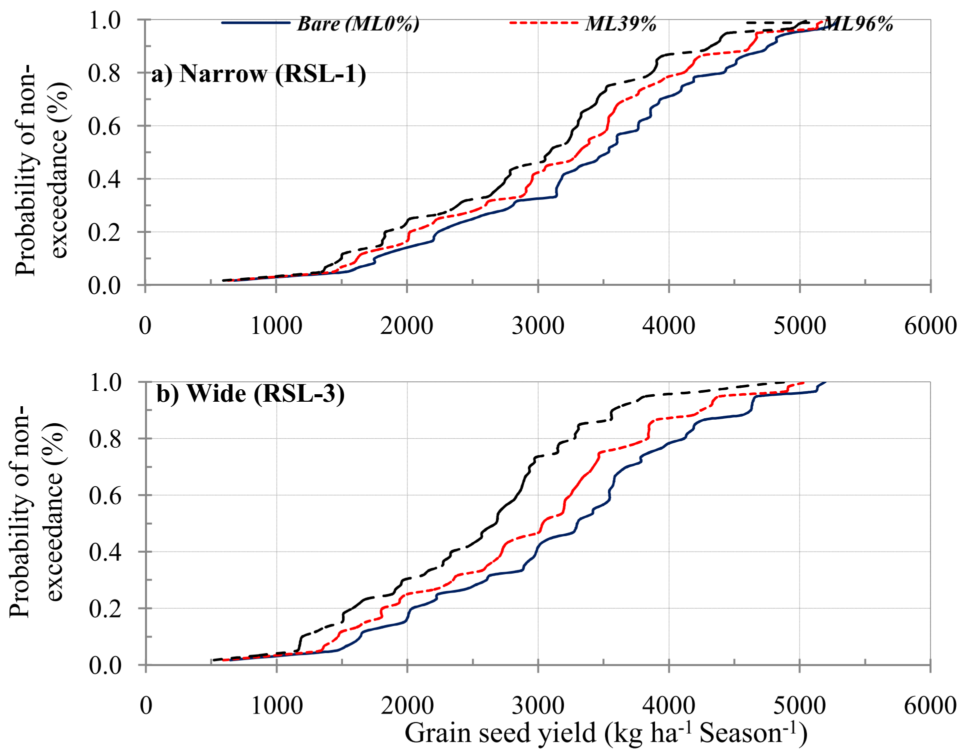
- Despite higher transpiration from full mulched wide had lower yield (2666.2 kg ha^{-1}) than the bare, probably because of the slightly stress effect during tasseling as a result of rapid water extraction.

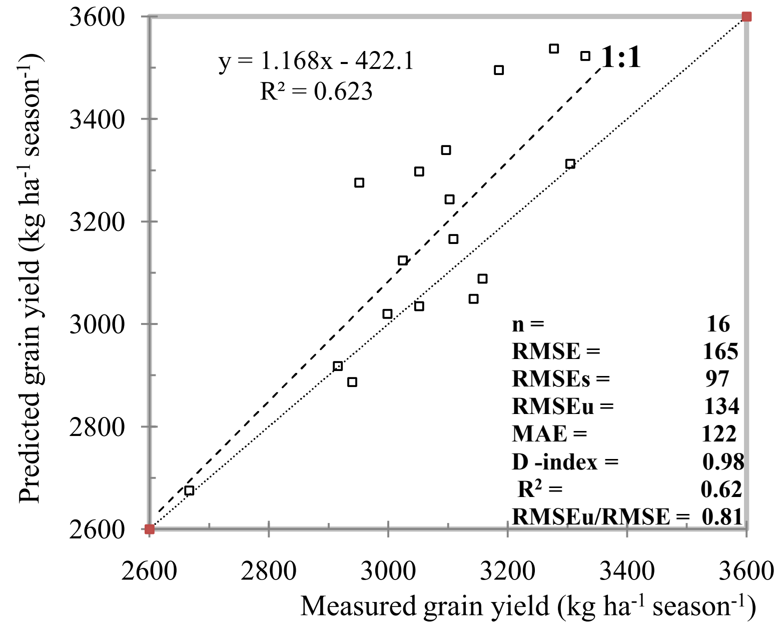
- Both bare & mulch narrow had the about same yield but the bare used less transpiration than mulched, thus the mulch is less productive than bare treatment.

. . . So what next. . . ???

. . . Is it possible to make **reliable recommendation for best / optimum** soil surface management strategies for IRWH? ??

For example, (Botha et al., 2003) use of **simple empirical CYPSA** model (only RF data) ???





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Concluding Remarks

- Kenilworth Bainsvlei ecotope has different features from the ecotopes where IRWH has been implemented before, with high clay contents and/or steeper slopes, these results tend to broader the application of IRWH.

- In many cases the biophysical properties of water harvesting are well understood & the ability of increase yield proven - - - -

  - - - but still lack of integrated approach to answer . . . .

- ***How the in-filed rainwater management help to support food production through using***
  crop growth simulation models & efficient decisions?

Source: Climate Hazard Group (USGS)

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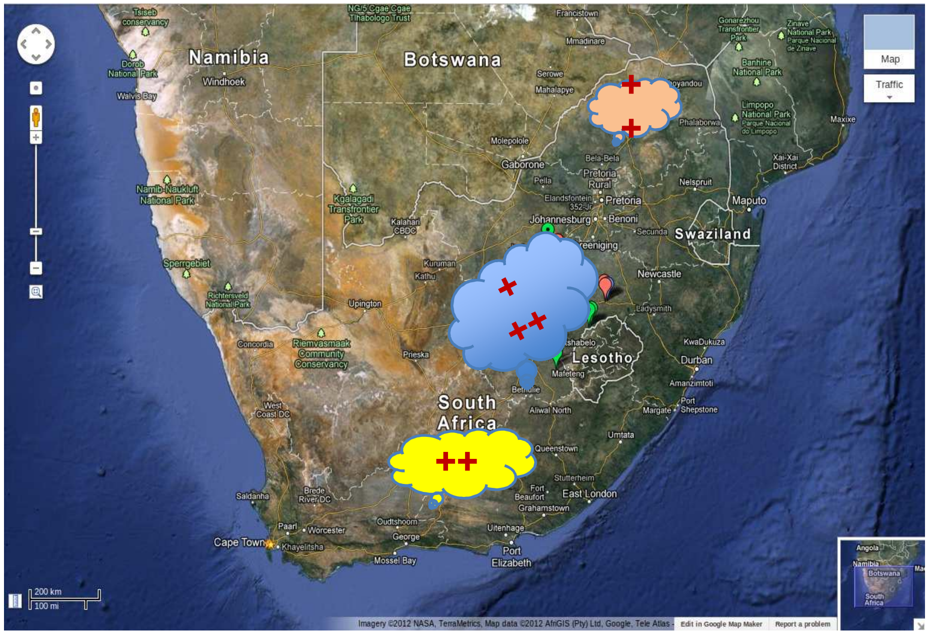
The Way Forward

- to evaluate the impact of optimal surface treatment strategies from small-scale maize production under mini-catchment runoff farming systems using both **APSIM and AquaCrop models.**

- **to develop adaptation strategies for efficient on-farm decision making using optimization**

Approach:



- ***Consider 6-8 locations in 3 regions***
- ***Use seasonal downscaled forecasts***
- ***Multi-Model application (APSIM & AquaCrop)***
- ***To use tactical decision the study will focus:***
  - ***Soil surface treatments***
  - ***Management adaptation strategies [sowing date and fertilization]***
- ***Efficient decision making / optimization***
- ***Communicating, disseminating & feedback***

Major outcome: evaluation & adaptation of the integrated approach of the combined effects of seasonal forecasts, crop models and optimisation procedures on-farm management decisions.

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Methodological Framework

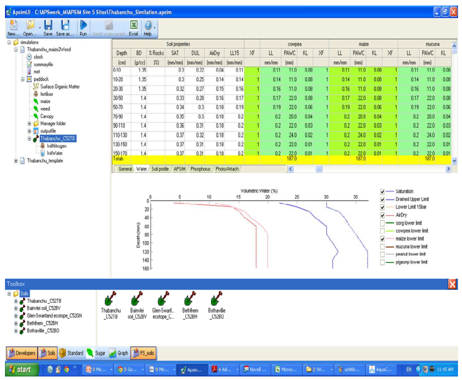
Input Data

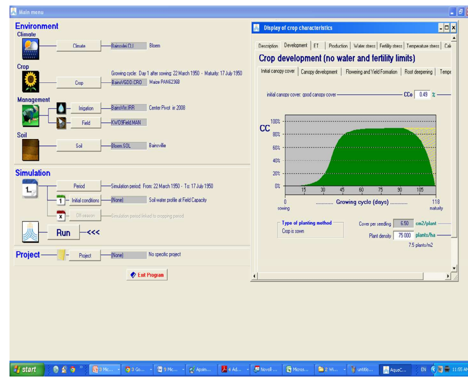
Long-term weather data
[Tmax, Tmin, RF, Rn, u, RH]

Detail soil info.
[BD, DUL, LL, Ksat, OC, PH, Texture, SW . . .)

Mgt. adapt. Strategies
[soil surface treatment, sowing date, fertilization]

Crop Models





OUTPUT-I
Model comparison & evaluation

Downscaled seasonal climate forecasts → **Application of Optimization Proc. (Using R-script tool)** → **OUTPUT-II** Assessment efficient decision making

OUTCOME → **Communication / Dissemination** → **Publications / Reports**

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Thank You
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T: 051 401 9111 info@ufs.ac.za **www.ufs.ac.za**

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