MSWG 2023

Rice & Malaria in Africa:

Suppressing the breeding of malaria vectors in rice fields

Our task

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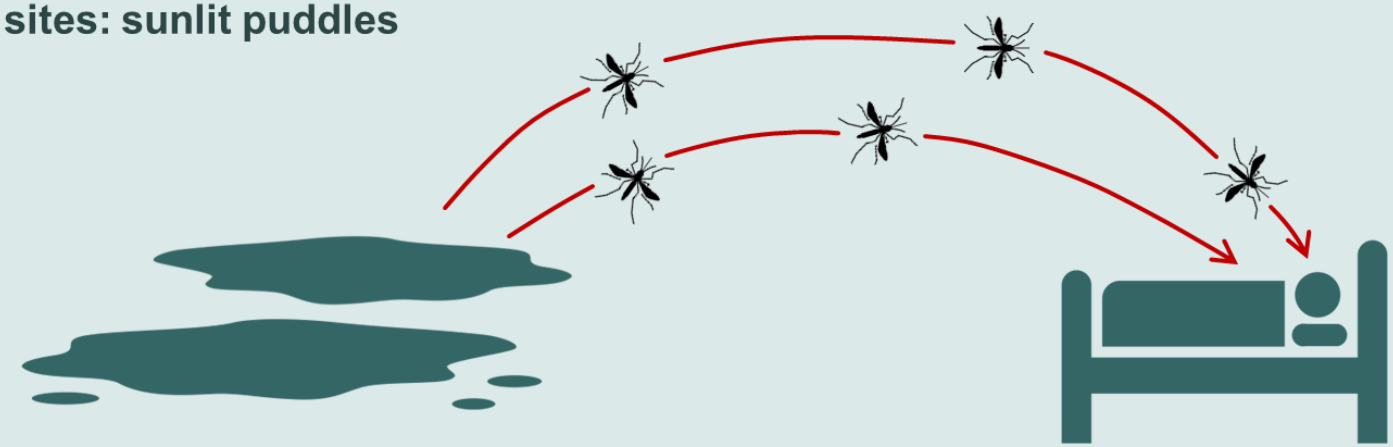
vs.

1990s: A series of studies in Africa
compared malaria in *rice vs. non-rice communities*

Paddies paradox: rice fields produce **VERY MANY EXTRA** malaria vectors but the malaria in rice villages was (at the time) similar or a bit less

Ordinary breeding sites: sunlit puddles

Moderate mosquito numbers



Humans without nets and poor access to drugs exposed to mosquitoes and parasites

Prolific breeding in rice fields

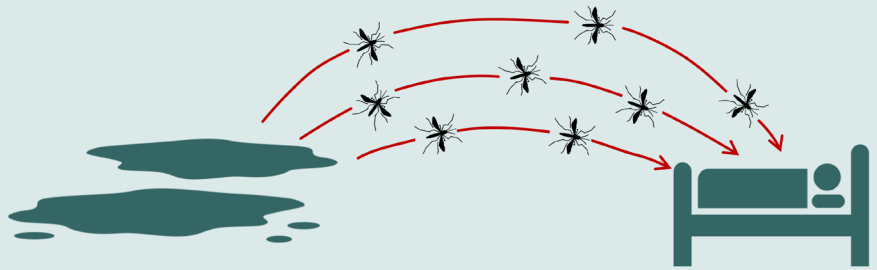
Superabundant mosquito numbers

Humans isolated by nets from mosquitoes, protected / cured of parasites through good access to drugs

THE COUNTERFACTUALS AND INEQUITIES OCCURRING IN COMMUNITIES

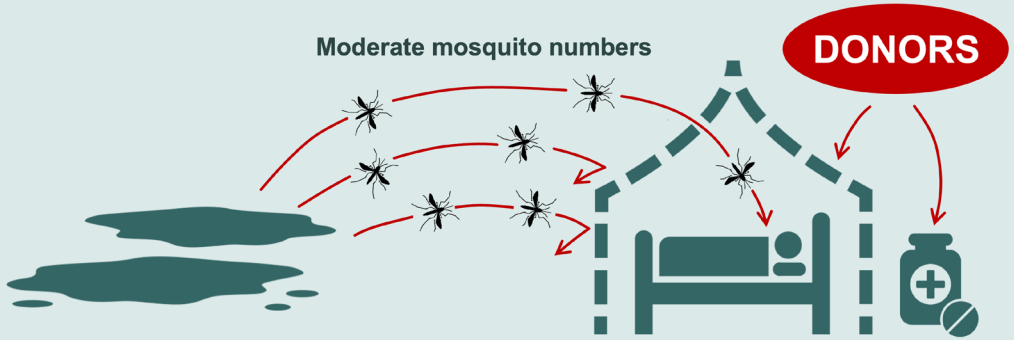
PRE-2003

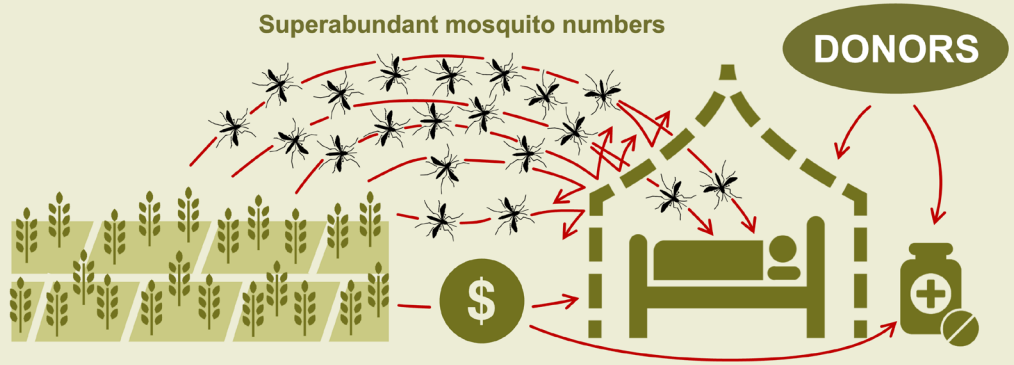
NON-RICE



RICE

POST-2003



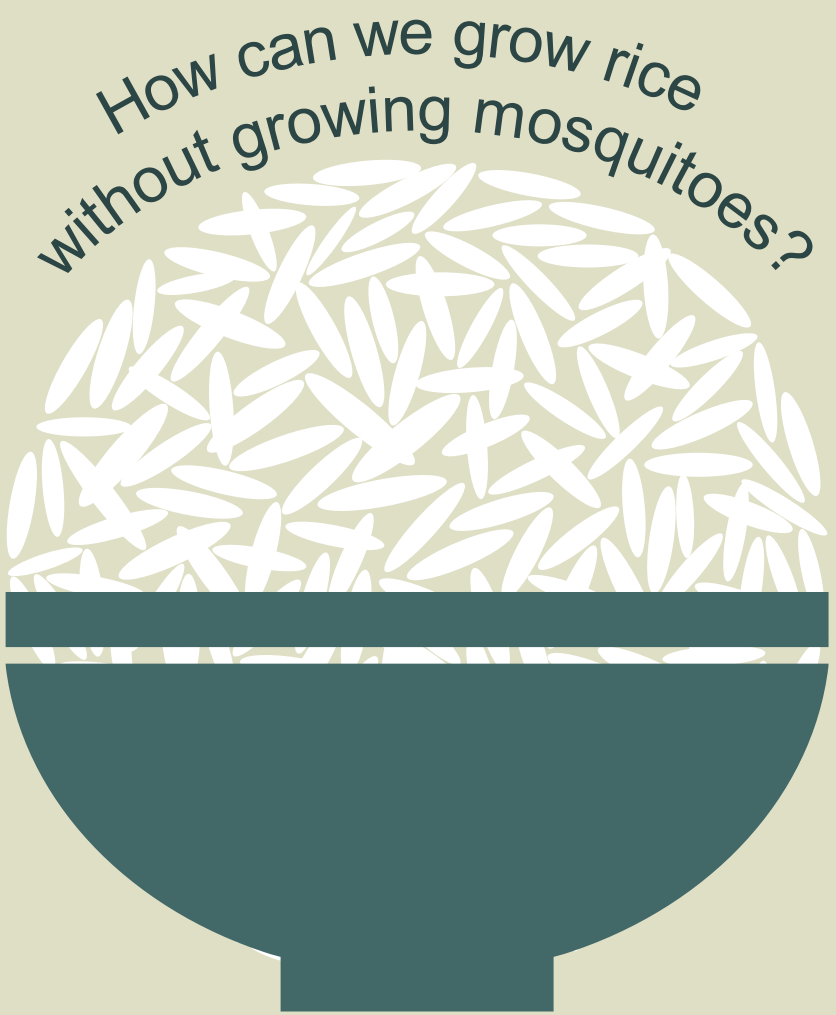


The relationship between rice and malaria will probably be an emerging problem for Africa

Whose problem?

Agricultural sector or public health sector?

1) We cannot stop/delay rice intensification
2) Nets and drugs are only partial and temporary solutions



	Does it work? (% effectiveness)	No. of studies (no. in SSA)
Monomolecular surface films	-57.2 (-69.4, -40.3) / -91.6 (-99.9, +486.3)	3 (3)
Biological larvicides	-60.0 (-71.8, -43.1)	10 (2)
Synthetic organic chemicals	-73.1 (-83.8, -55.4) / -72.3 (-89.5, -26.9)	6 (2)
Fish	-81.5 (-91.4, -60.2) / -87.1 (-93.9, -72.7)	6 (1)
Copepods	-40.5 (-82.8, +105.6)	1 (0)
Azolla		1 (0)
Neem		1 (0)
Intermittent irrigation		7 (2)
Rice variety		1 (0)
Rice variety & plant spacing	-66.3 (-90.0, +13.4)	1 (0)
Weed control (herbiciding)	+77.4 (+65.7, +89.9)	1 (0)
Agricultural insecticide	-76.4 (-88.8, -50.2)	1 (0)
Land preparation: tillage	-64.7 (-85.5, -14.1)	1 (1)
Land preparation: levelling	-12.8 (-65.2, +118.5)	1 (1)

It is possible!

Rice experts should know
– sooner and better than anyone else – **what effect their recommended production methods have on mosquitoes**

- Rice yield
- Water consumption
- Labour intensity
- Weed production

Our task

1. More (and better) evidence on the rice-malaria relationship
2. The rice attributable fraction of malaria
3. Better riceland mosquito monitoring methods

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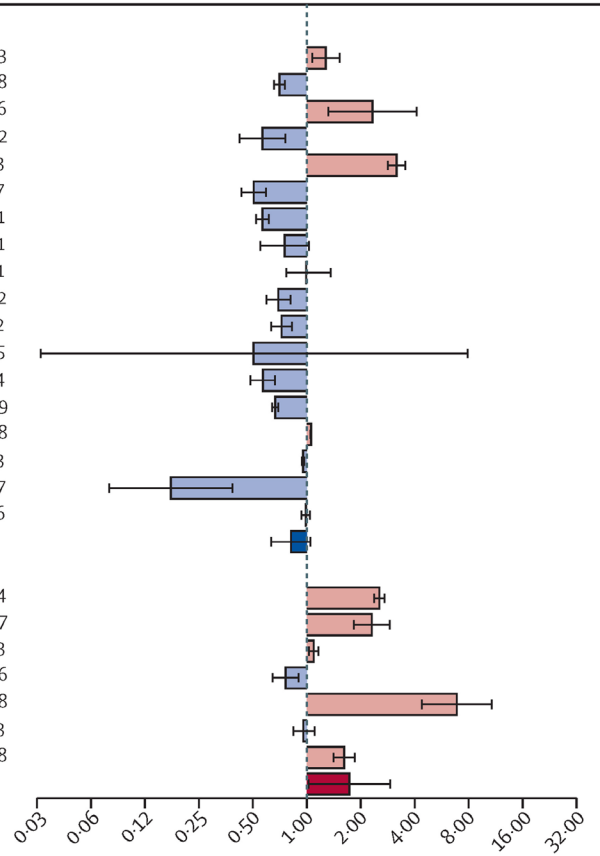
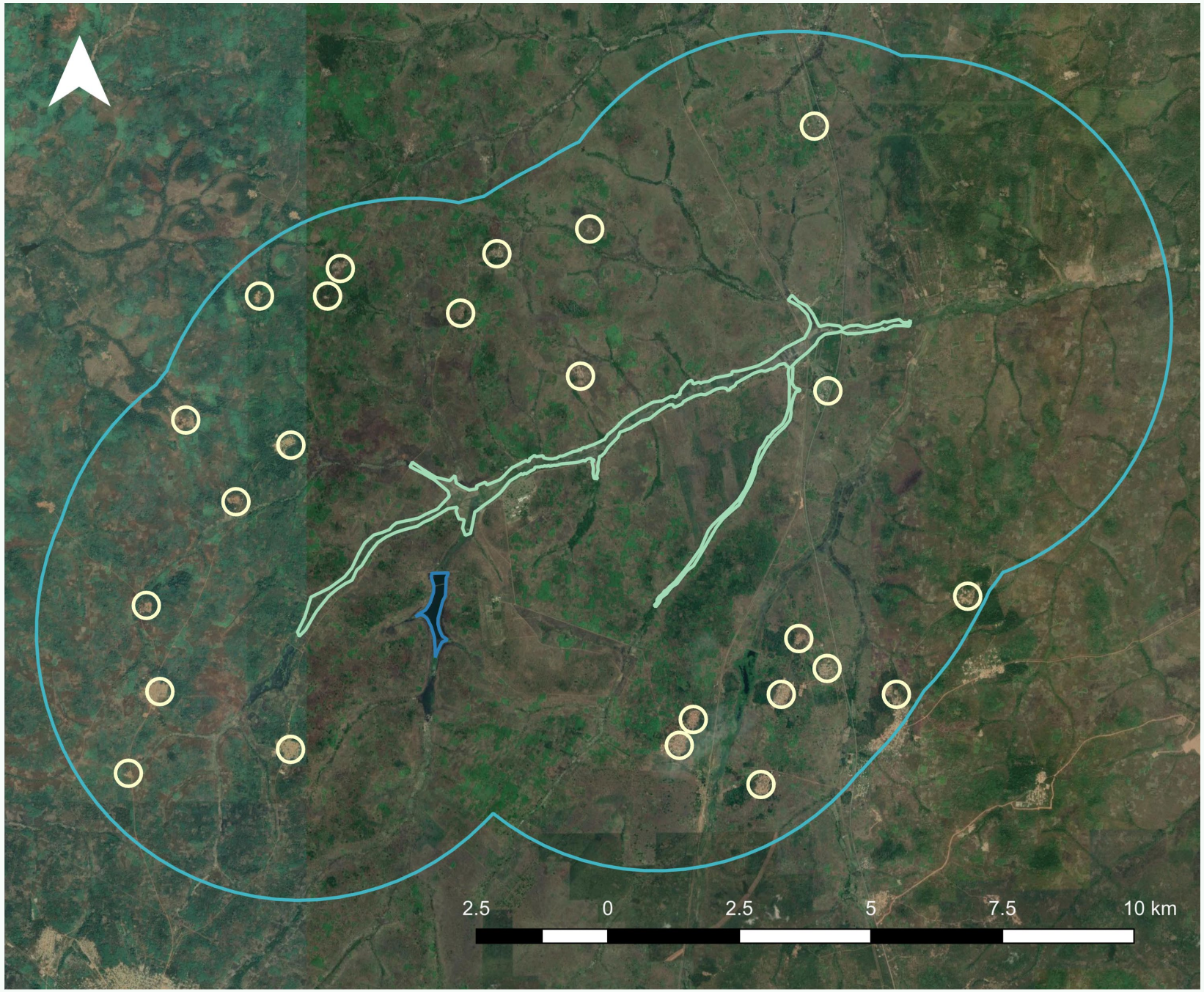
	Country	Year	Control areas		Rice-growing areas		Risk ratio (95% CI)
			Total participants	*Pf*PR$_{2-10}$	Total participants	*Pf*PR$_{2-10}$	
Pre-2003 studies							
Audibert et al (1990)[26]	Cameroon	1979	1470	19·4558	491	24·8473	1·28 (1·06–1·54)
Robert et al (1987)[27]	Burkina Faso	1980	817	62·4235	1505	43·8538	0·70 (0·65–0·76)
Couprié et al (1985)[29]	Cameroon	1981	554	3·2491	370	7·5676	2·33 (1·31–4·15)
Audibert et al (1990)[26]	Cameroon	1981	775	12·5161	864	7·0602	0·56 (0·42–0·77)
Coosemans (1985)[29]	Burundi	1982	1335	17·2045	2357	54·7553	3·18 (2·81–3·60)
Josse et al (1987)[32]	Cameroon	1985	966	26·9151	1409	13·5557	0·50 (0·43–0·60)
Boudin et al (1992)[33]	Burkina Faso	1985	1033	62·8359	1087	35·4221	0·56 (0·51–0·62)
Audibert et al (1990)[26]	Cameroon	1985	469	14·7122	542	11·0701	0·75 (0·54–1·04)
Faye et al (1993)[37]	Senegal	1990	685	9·6825	1035	9·7871	1·01 (0·75–1·36)
Thomson et al (1994)[39]	The Gambia	1991	1167	50·3844	298	35·0622	0·69 (0·59–0·82)
Gbakima (1994)[38]	Sierra Leone	1991	105	68·9089	1001	49·5132	0·72 (0·63–0·83)
Faye et al (1995)[40]	Senegal	1992	329	0·3180	656	0·1595	0·50 (0·03–7·99)
Ijumba et al (2002)[43]	Tanzania	1994	1483	21·4820	1468	12·2114	0·57 (0·48–0·67)
Sissoko et al (2004)[47]	Mali	1995	3308	51·0108	5826	33·9839	0·67 (0·63–0·70)
Henry et al (2003)[49]	Côte d'Ivoire	1997	11951	83·2694	24266	88·0288	1·06 (1·05–1·07)
Assi et al (2013)[52]	Côte d'Ivoire	1998	8189	50·7864	21141	48·5513	0·96 (0·93–0·98)
Mutero et al (2004)[55]	Kenya	2001	116	38·9543	90	7·0057	0·17 (0·08–0·38)
Koudou et al (2009)[58]	Côte d'Ivoire	2002	245	90·9072	171	90·1236	0·99 (0·93–1·05)
Pooled effect estimate							0·82 (0·63–1·06)
Post-2003 studies							
Rumisha et al (2019)[64]	Tanzania	2004	3283	18·7713	4605	47·8074	2·55 (2·36–2·75)
Mboera et al (2011)[66]	Tanzania	2005	289	22·6452	289	51·8647	2·31 (1·81–2·94)
Koudou et al (2009)[58]	Côte d'Ivoire	2005	795	63·7318	714	69·6313	1·09 (1·02–1·17)
Touré et al (2016)[70]	Mali	2010	417	34·7716	728	26·5096	0·76 (0·64–0·91)
Mboera et al (2015)[73]	Tanzania	2012	1016	1·9322	1022	13·6478	6·91 (4·36–10·95)
Hien et al (2017)[74]	Burkina Faso	2014	329	55·6231	285	53·3333	0·96 (0·83–1·11)
Babamale et al (2020)[75]	Nigeria	2018	137	58·9749	93	95·9538	1·62 (1·40–1·87)
Pooled effect estimate							1·73 (1·01–2·96)



More evidence on the rice-malaria relationship:

- Longitudinal studies (comparing malaria risk before and after rice introduction)
- Geospatial analyses of rice distribution and malaria indicators (extra consideration needed!)
- Include ento + epi (clinical) indicators
- Questions of equity



The rice-attributable fraction of malaria

- More evidence on the effect of rice cultivation on malaria risk
- Learning from climate change agronomists…

Vector productivity

Total number of *An. gambiae s.l.* produced per hectare of rice in a cropping season

Number of pupae per hectare of rice on day t

Prop. of late-stage larvae and pupae that are *An. gambiae s.l.* (4.7-56.8% depending on growing phase t)

Prop. of late-stage larvae and pupae that are female (50.6%)

No. of days in a cropping season (161 days)

Per capita rate at which adults emerge from pupae (0.85 adults per pupa per day)

$$A = \sum_{t=1}^{T} X_t \times p_t^{An} \times p_{female} \times \gamma,$$

The mean number of pupae collected per dip in growing phase s in quadrats at distance d from edge of plot (1=land preparation, 2=vegetative, 3=reproductive, 4=ripening & post-harvest)

Scaling factor of a standard sized plot to a hectare (which is 39.1 for a plot of 256 m^2 and a hectare of 10,000 m^2)

Duration in days of growing phase s

$$\sum_{t=1}^{T} X_t = \sum_{s=1}^{4} \left(\sum_{d} \bar{x}_{s,d} \times e^{-\varphi \times d} \times Q_d \right) \times \beta \times \theta \times T_s$$

Reduction in the number of pupae for each metre from closest edge (0.479)

The total number of quadrats in a plot at distance d from edge (which is 1024 for a plot of 256 m^2)

Dip-quadrat calibration factor (obtained from zero-intercept linear regression) corresponding to the expected number of pupae in a quadrant (0.25m^2) for each pupa sampled in a dip

Total no. of *An. gambiae* s.l. females produced per hectare of rice in a cropping season	**723 thousand** (95% CI 593 – 852)
Total no. of *An. gambiae* s.l. females produced in M'bé irrigation scheme (140 ha) in a season	**103 million** (95% CI 84.5 – 121.4)

Better riceland mosquito monitoring methods

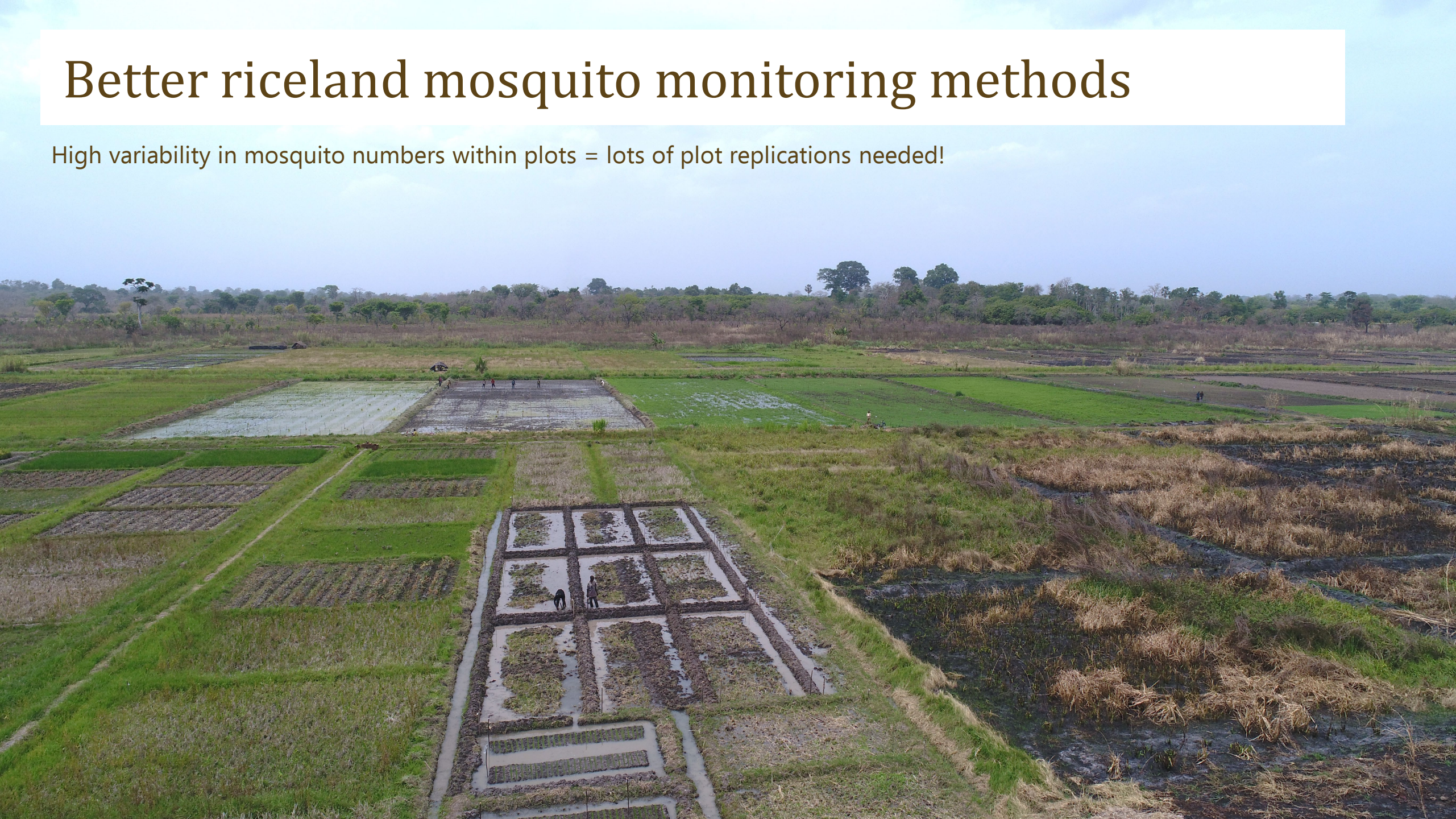
- Current methods of dipping = too laborious and subjective

Promising ideas…

- eDNA
- Image analysis

Better riceland mosquito monitoring methods

High variability in mosquito numbers within plots = lots of plot replications needed!



Better mosquito monitoring design and techniques are required – to be built into regular rice research

Rice-attributable burden of malaria?

- Reduce water use
- Reduce methane emissions
- No rice yield penalty
- Reduce malaria vector production

TRANSDISCIPLINARY WIN-WIN-WIN-WIN SOLUTION