Photo Credit: LRI/Stevie Mann - Ploughing with cattle in southwestern Ethiopia

PROMOTING AGRICULTURAL TECHNOLOGY IN THE NILE BASIN

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Future of the Nile Water Workshop, MIT, April 26-27, 2018

MIT | Civil and Environmental Engineering

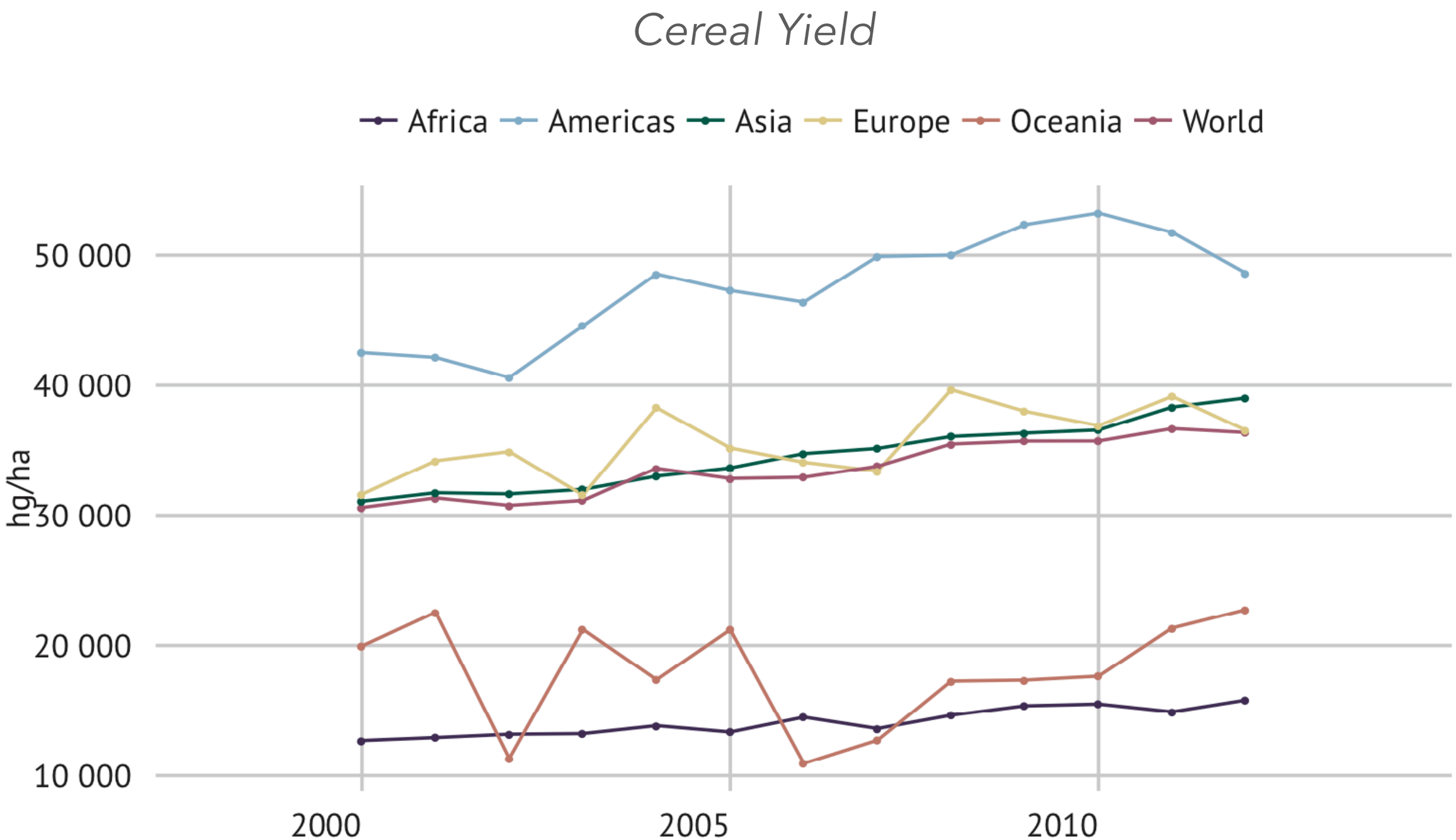


Figure Source: FAO Statistical Pocketbook: World Food and Agriculture (2015), page 28, Figure 48

A New Path to African "Fertility"

Application of Agricultural Technologies to:

- Improve Yields
- Increase Water Use Efficiency

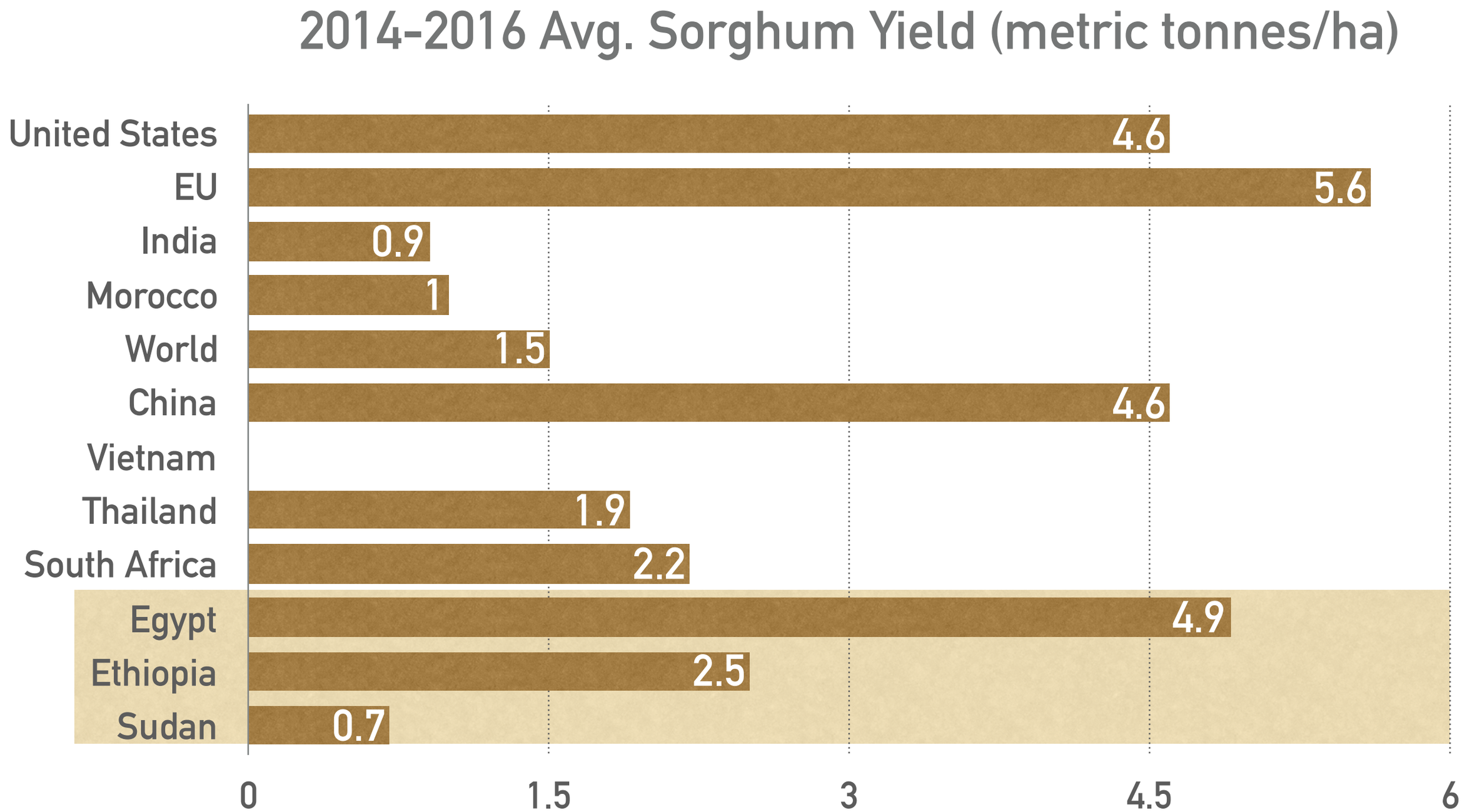
https://www.trustnodes.com/wp-content/uploads/2017/09/green-shoots.jpg

AGRICULTURAL CHARACTERISTICS

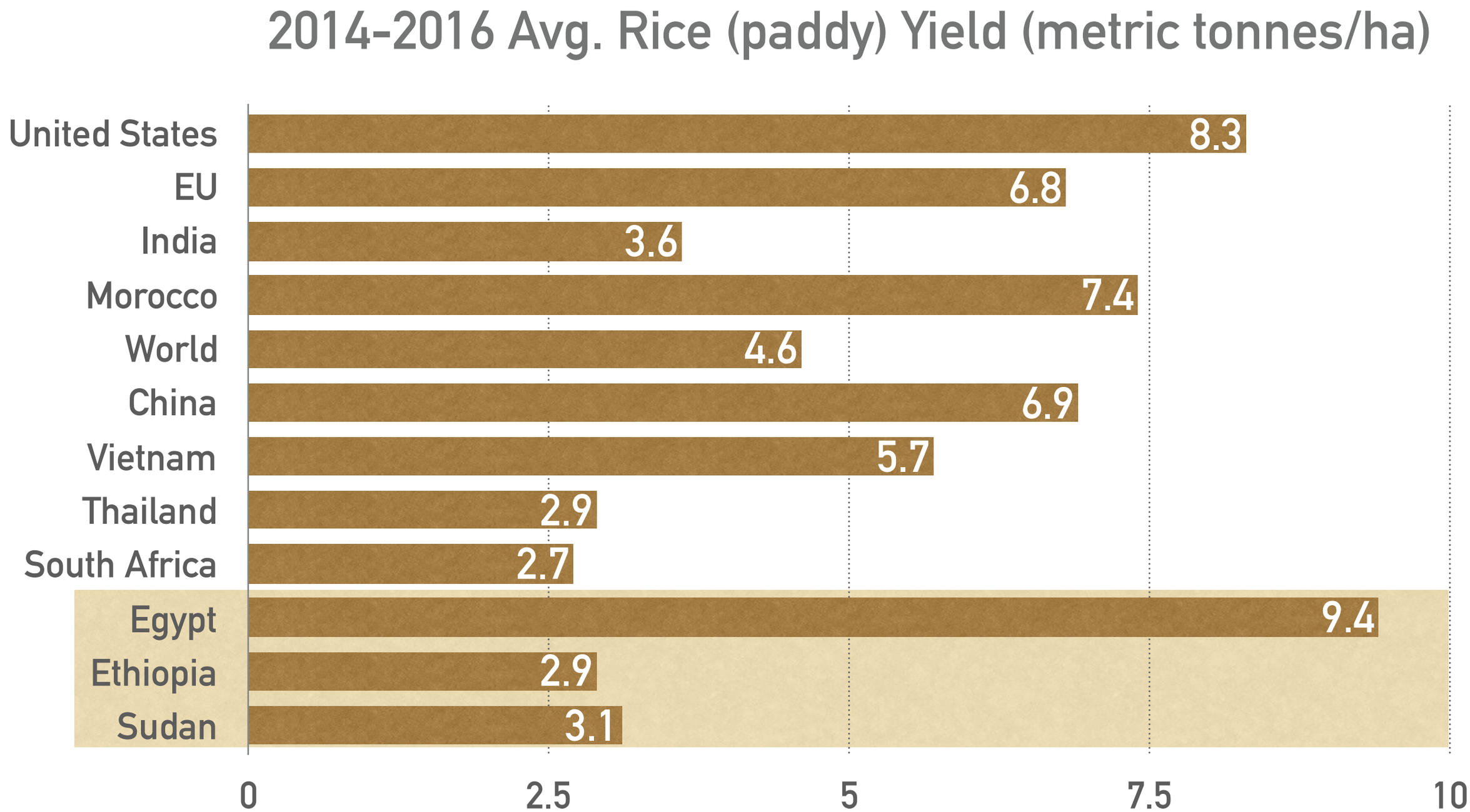
Permanent Meadows + Pasture + Cultivated Land

Arable Land + Permanent Crops

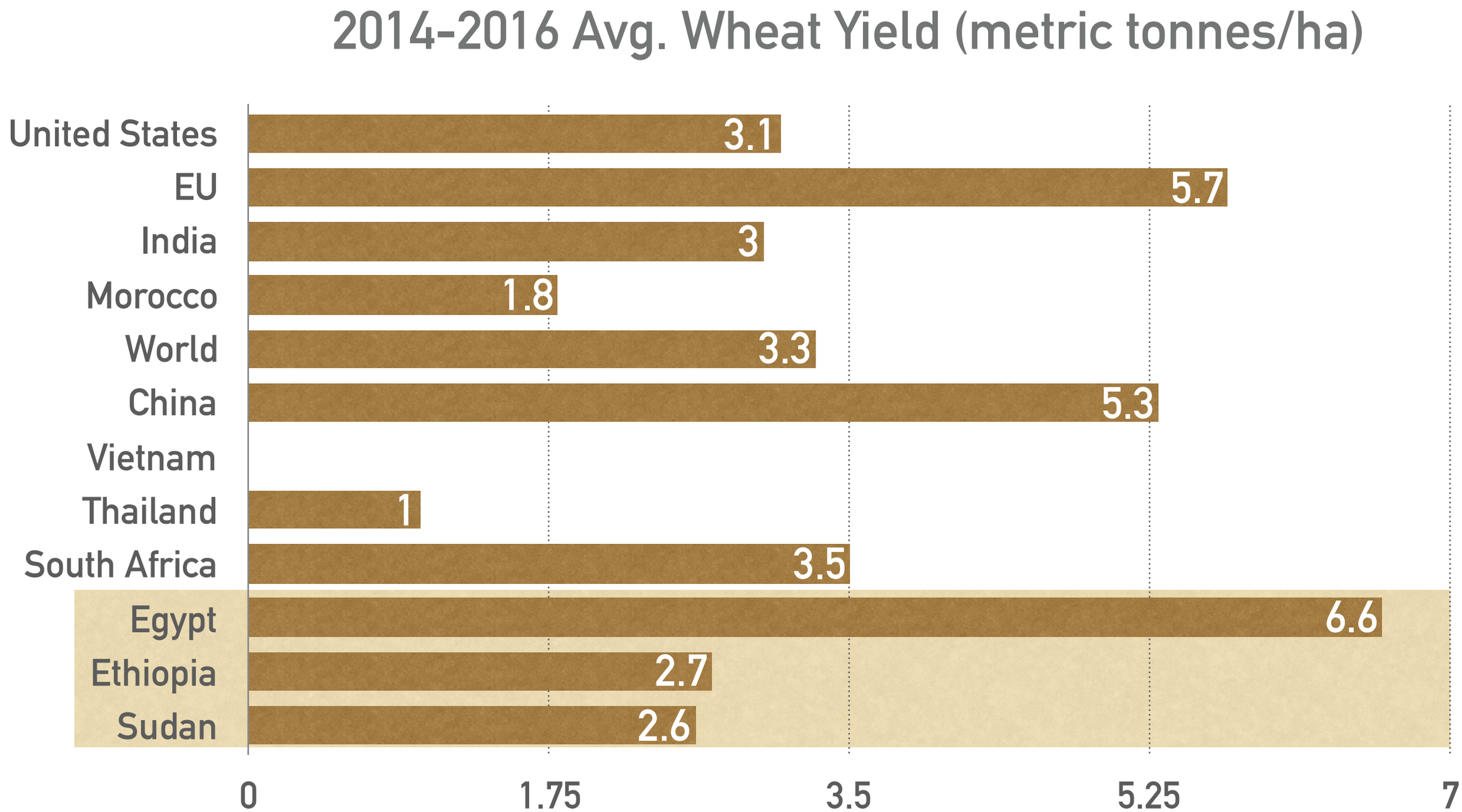
	Dominant Holding Type	Main Advantages and Disadvantages	Agricultural Area (percent of total)	Cultivated Area (percent of total)
Egypt	Small Holder (50% < 0.42 ha)	✦ Encroaching Urbanization ✦ Highly Productive, gains available in water use efficiency	3,761,000 ha (4%) (FAO Aquastat, 2013)	3,761,000 ha (4%) (FAO Aquastat, 2013)
Ethiopia	Small Holder (Avg. < 1 ha)	✦ Increasing productivity and fertilization ✦ Lacks storage and irrigation capacity	36,259,000 ha (33%) (FAO Aquastat, 2013)	16,259,000 ha (15%) (FAO Aquastat, 2013)
Sudan	Small Holder	✦ Poor Productivity ✦ Potential for horizontal Expansion	112,702,000 ha (60%) (FAO Aquastat, 2012)	21,252,000 ha (11%) (FAO Aquastat, 2012)



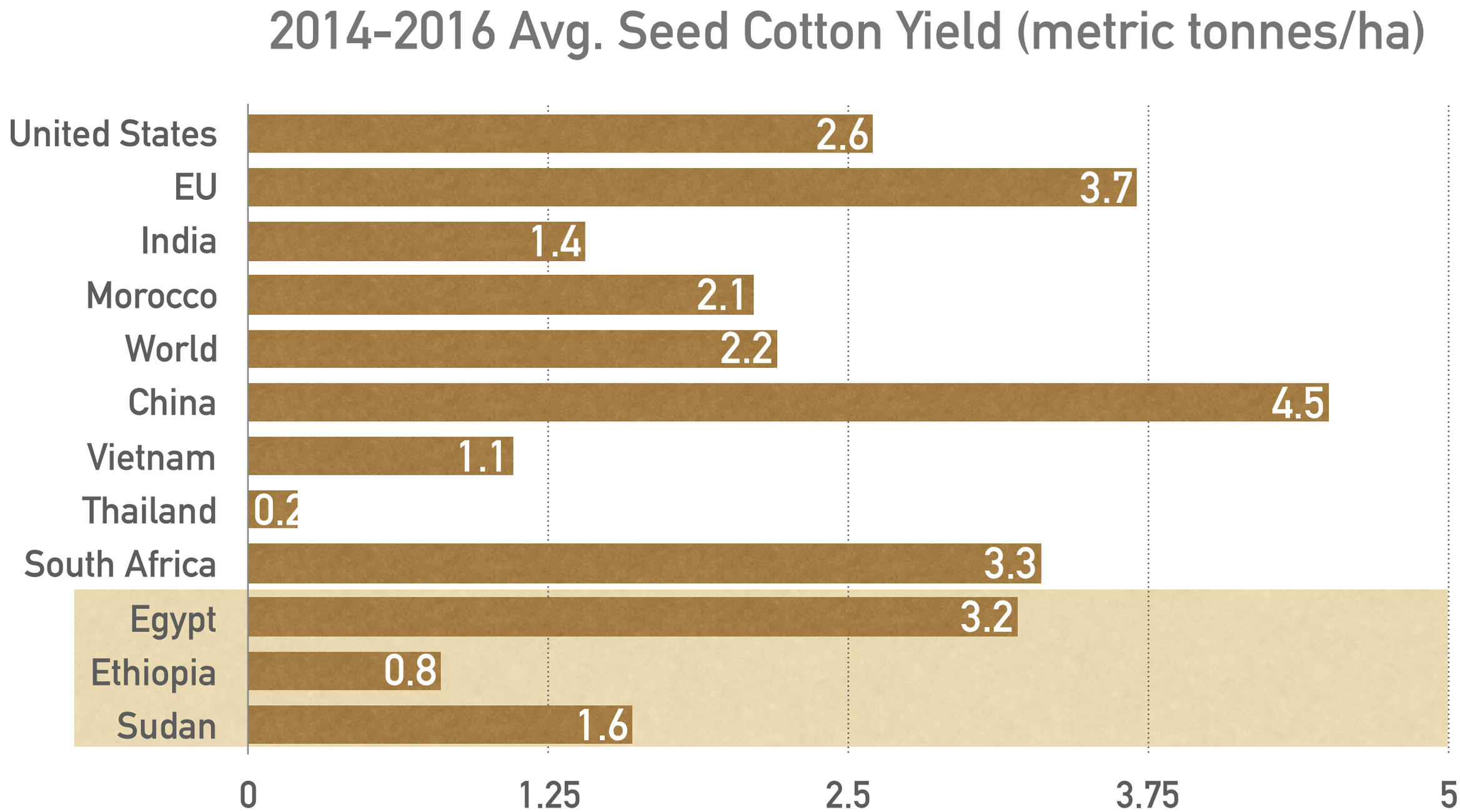
Source: FAOSTAT



Source: FAOSTAT

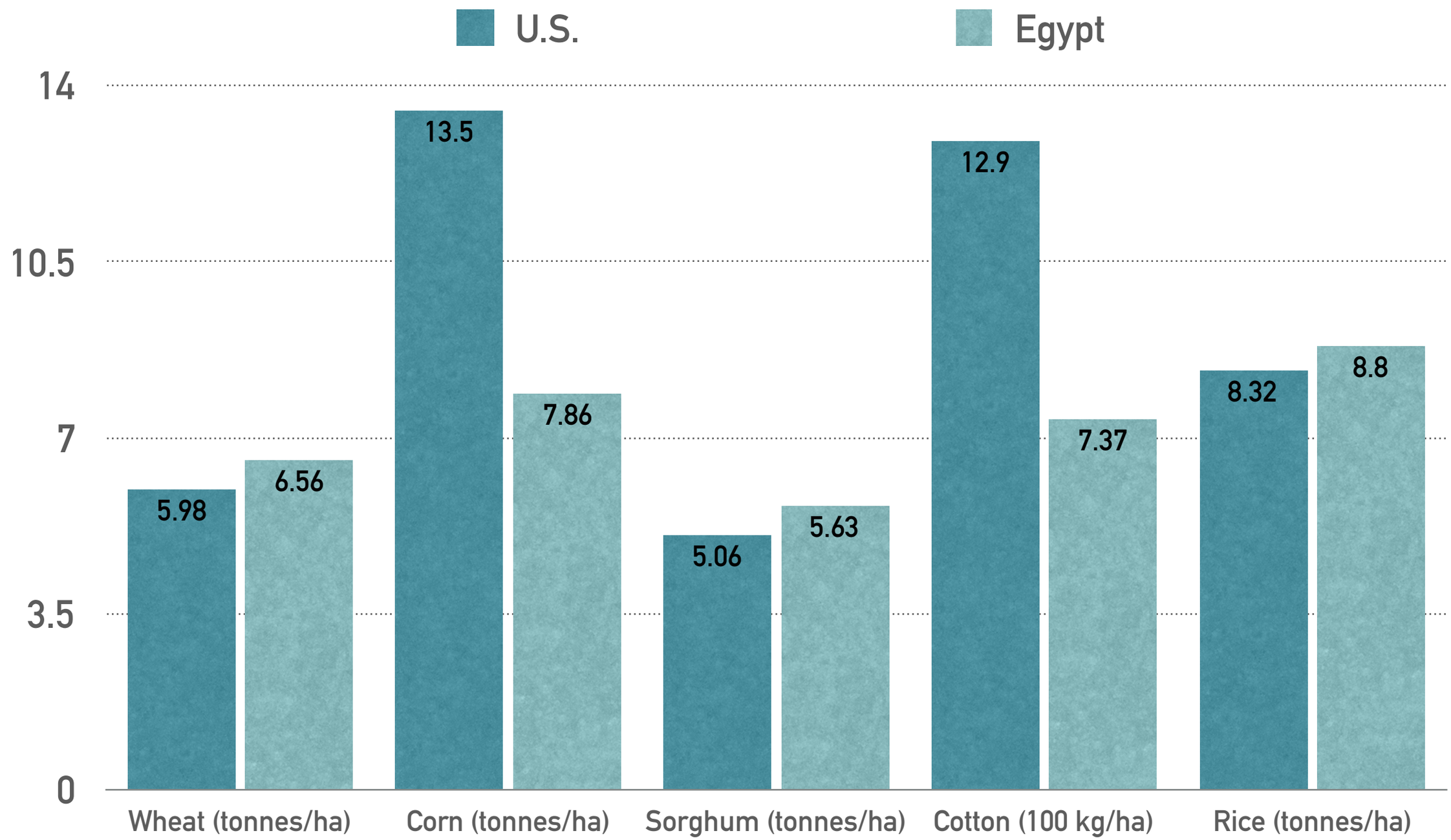


Source: FAOSTAT



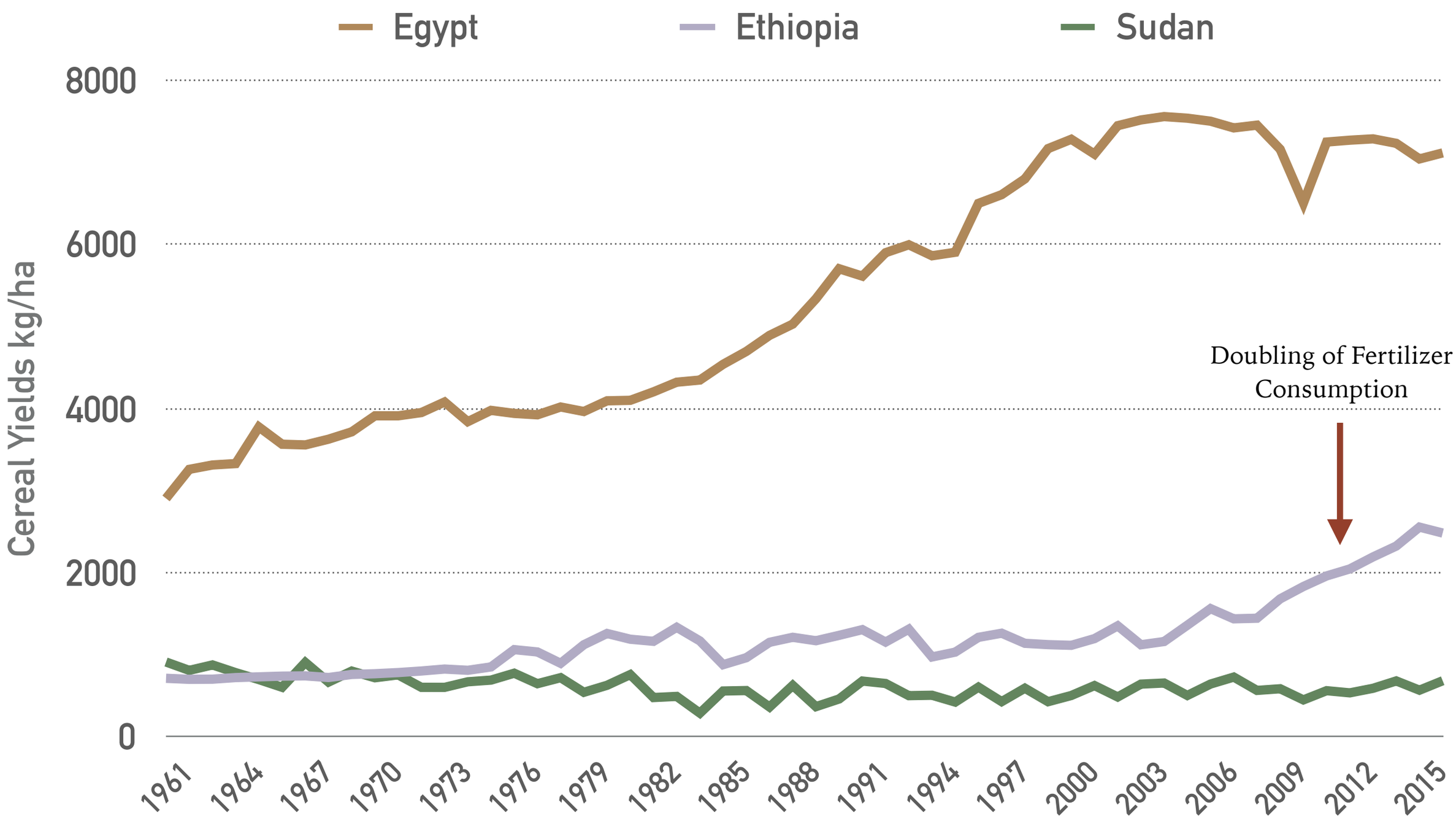
Source: FAOSTAT

IRRIGATED YIELDS

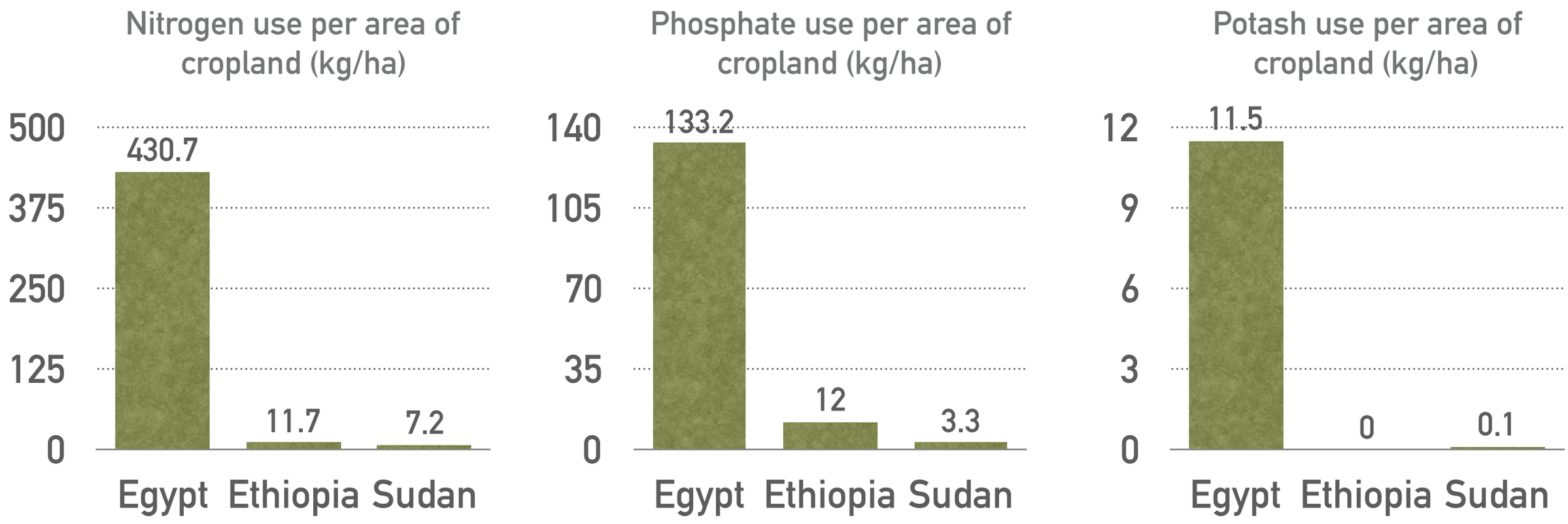


Egypt Values: USDA FAS (2013) for year 2011/2012; United States Values: USDA (2014) for year 2012

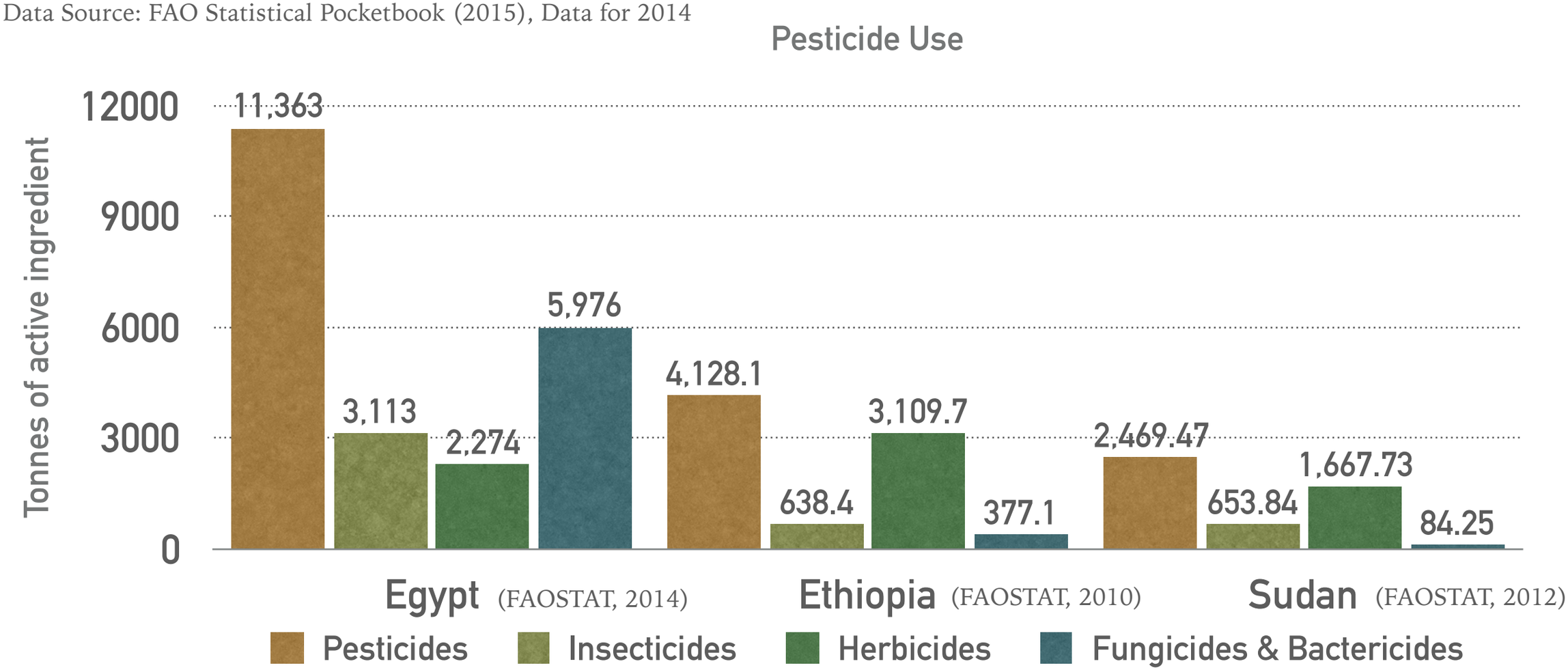
YIELDS OVER TIME



Source: World Bank (2018)

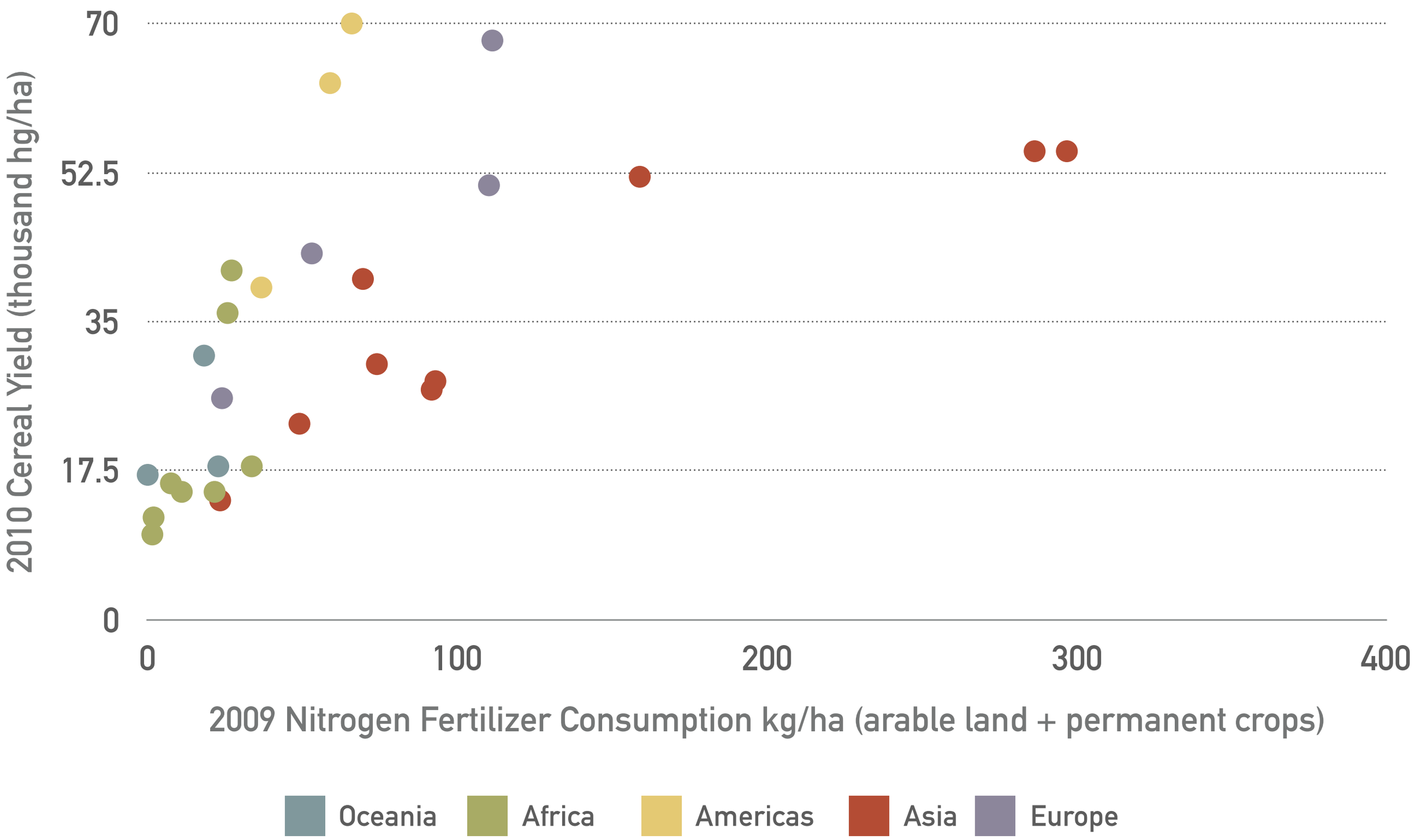


Data Source: FAO Statistical Pocketbook (2015), Data for 2014



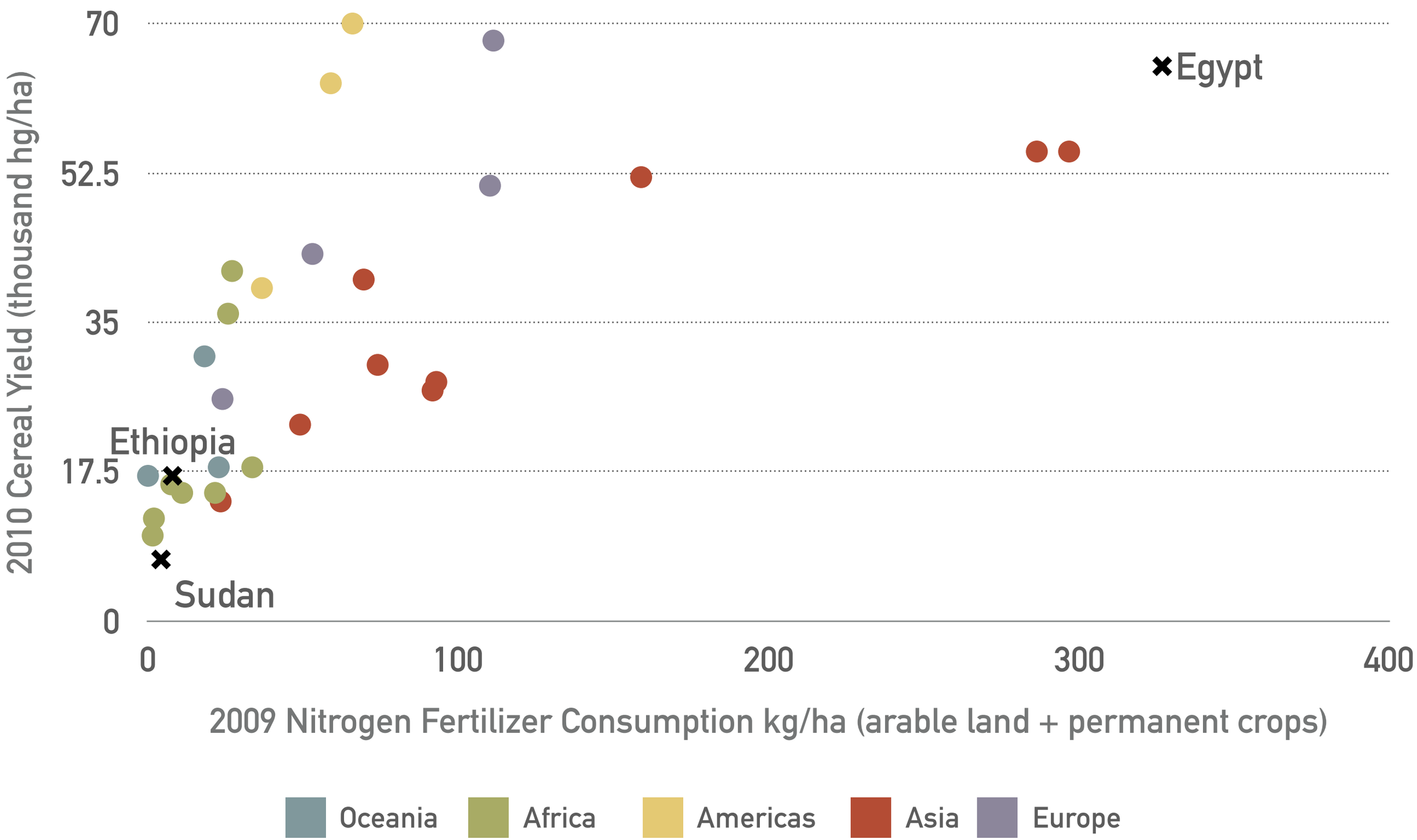
FERTILIZER V. YIELD RELATIONSHIP

Data: FAO Statistical Yearbook 2013, FAO Statistical Pocketbook 2015 (Sudan Fertilizer (2014))

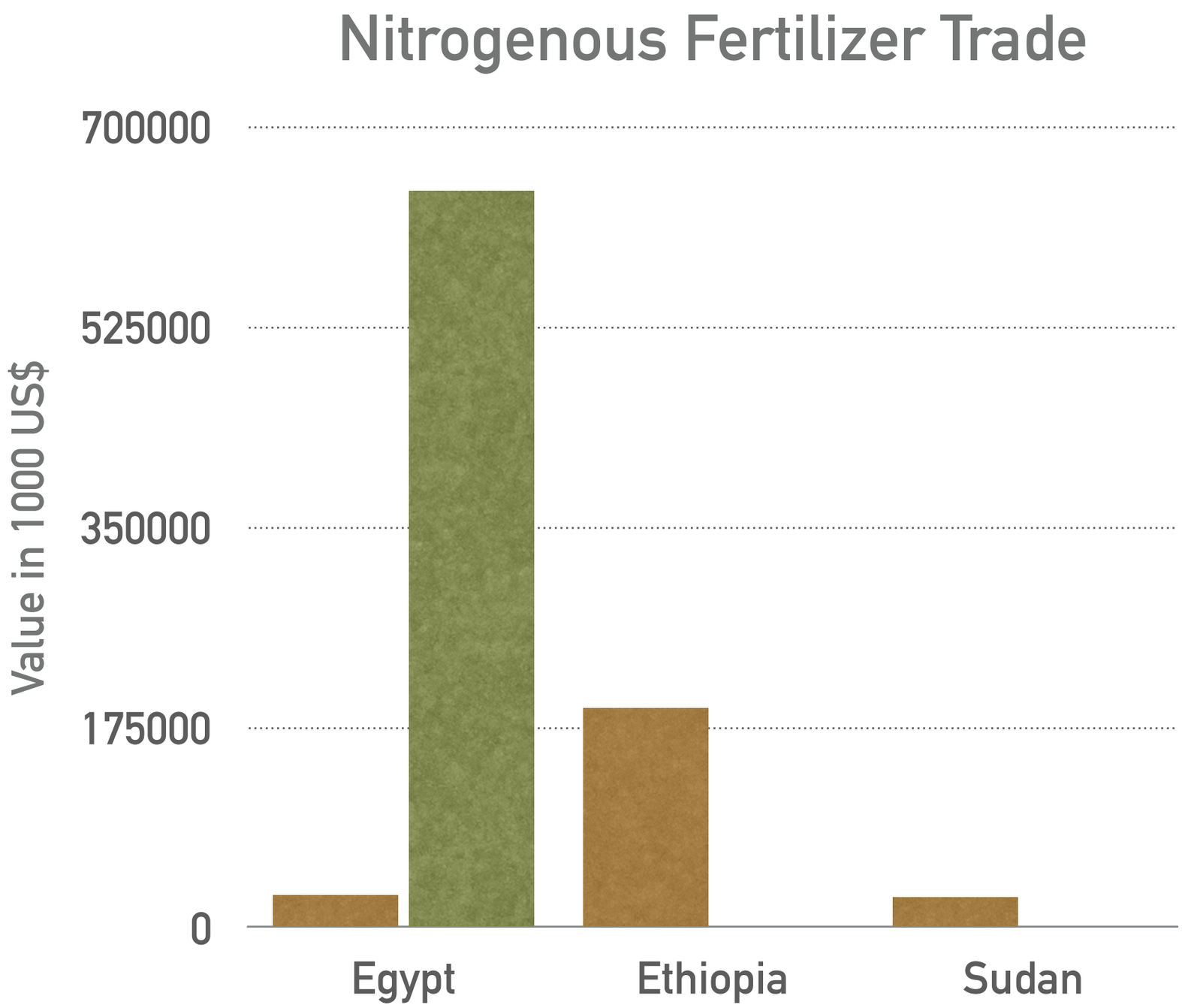


FERTILIZER V. YIELD RELATIONSHIP

Data: FAO Statistical Yearbook 2013, FAO Statistical Pocketbook 2015 (Sudan Fertilizer (2014))



FERTILIZER TRADE



Source: FAOSTAT, 2014 data for Egypt and Ethiopia, 2012 data for Sudan

62% of Egyptian Exports of Nitrogen Fertilizer go to Europe: France (21%), Italy (13%), Spain (10%)

1.8% of Egyptian Exports of Nitrogen Fertilizer are to African nations

(Source: OEC)

IRRIGATION AREA

Egypt

- **Cultivated Area**: 3.7 million ha
- **3.6 million ha** equipped for full control in 2010 (2.7 million ha (76%) in Old Lands).
- 100% of equipped area irrigated in 2002.

(Source: FAO Aquastat, FAO Statistical Yearbook 2014)

Ethiopia

- **Cultivated Area**: 16.2 million ha
- Estimates range widely from 91,000 ha equipped (NBI 2016) to **658,000 ha** equipped for full control in 2014/2015. (1.9 million ha water managed) (FAO Aquastat)
- Again, estimates of actual irrigated percentage of equipped area range from 70-100% (FAO Aquastat; FAO Statistical Yearbook, 2013)

(Source: FAO Aquastat)

Sudan

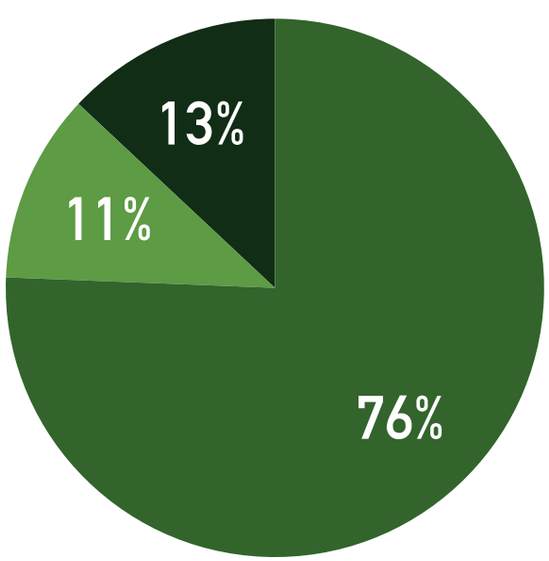
- **Cultivated Area**: 21.3 million ha
- **1.9 million ha** equipped for full control irrigation in 2014
- 50-60% of equipped area irrigated in 2011. 43% in 2000

(Source: FAO Aquastat, FAO Statistical Pocketbook (2015))

IRRIGATION TECHNOLOGY USED (Sources: FAO AQUASTAT Profiles)

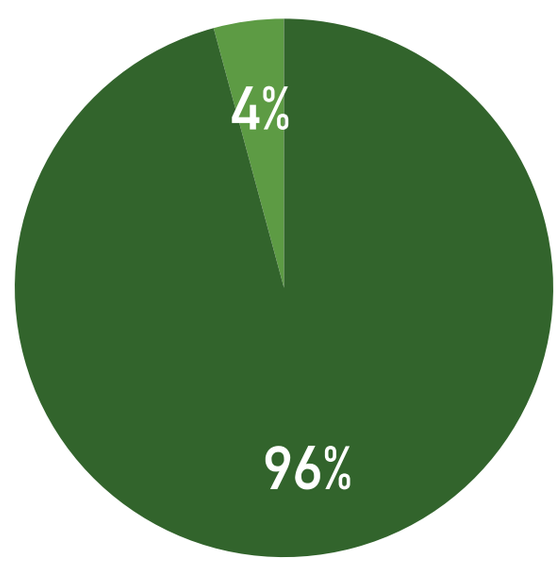
Egypt

- 16 km^3 of drainage water, 6 km^3 reused (2011 Est.). 88% of irrigation area is drained
- Rainwater harvesting in North Sinai and Northwest Coast (133,500 ha)
- Field efficiency estimated at 50% in 2007 (FAO Egypt CPF, 2013)



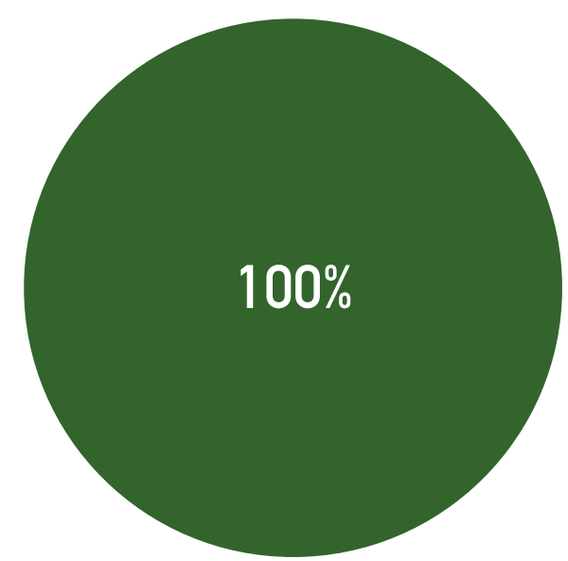
Ethiopia

- Gravity drainage, but not widely implemented except in irrigated lands
- Well-developed rainwater harvesting (128,000 ha)



Sudan

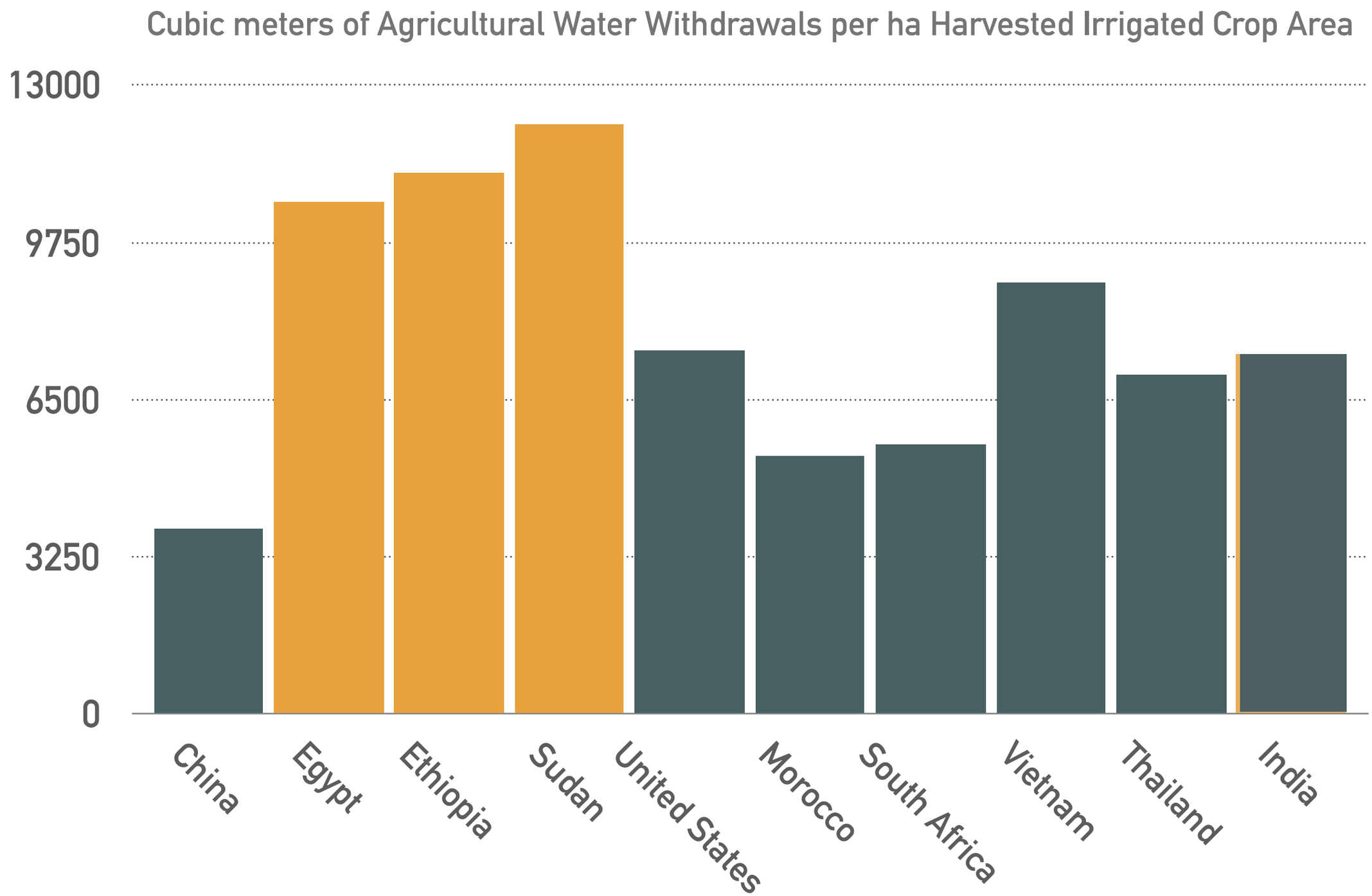
- Estimate of 500,000 ha drained in pre-2011 Sudan
- Surface gravity method and canals.



Surface Sprinkler Localized

*Assumed based on lack of specific data

WATER USE



(Data Source: FAO Aquastat - Data Presented for China (2005 Withdrawal, 2006 Area), Egypt (2010 Both), U.S. (2010 Withdrawal, 2008 Area), Morocco (2010 Withdrawal, 2011 Area), South Africa (2013 Withdrawal, 2008 Area), India (2010 Withdrawal, 2013 Area), Vietnam (2005 Both), Thailand (2007 Both); Sudan Withdrawals (Salman M.A. Salman (2011), NBI (2016) and Area (NBI (2016))); Ethiopia Area and Withdrawals (NBI (2016)))

VIRTUAL WATER (CASCAO, 2017; ZEITOUN ET AL., 2010)

- Egypt **imports 32-34 bcm of Virtual Water**, mostly through food ~ this is equivalent to about 40% of their water consumption figure
- Ethiopia is a **net VW exporter**, and most of the exports (coffee) are grown through "green" water. However these exports total roughly 1 bcm (Zeitoun et al., 2010).
- Approximately **2% of VWT occurs within the Nile Basin** region (Zeitoun et al., 2010).
- **Potential for increasing regional trade and cooperation! (Cascao, 2017)**

METHODS FOR INCREASING AGRICULTURAL PRODUCTIVITY AND WATER USE EFFICIENCY

https://commons.wikimedia.org/wiki/File:Palissage_et_irrigation_du_vignoble_de_Paarl.jpg

IRRIGATION

- Irrigation not only increases **yield**, but reduces **inter-annual variability**. (Otsuka and Larson, 2013; Kucharik and Ramankutty, 2005)
- **Lining canals** and switching to **drip and other localized irrigation systems** ensure that more water is transpired rather than going to drainage (Brouwer et al., 1989)
  - However increased efficiency does not automatically translate to water savings without controls on overall consumption (Perry & Steduto, 2017)
- Institutional supports such as **guaranteeing water delivery and cost sharing** of upgrades can incentivize investment (FAO RNE)
- Potential for **"supplemental irrigation"** and the expanded management of rainwater for this purpose. Can increase cropping cycles and smooth out variability (Oweis and Hachum, 2006; Hengsdijk et al., 2014; Rockstrom et al., 2009)

	Earthen canals			Lined canals
Soil type	**Sand**	**Loam**	**Clay**	
Canal length				
Long (> 2000m)	60%	70%	80%	95%
Medium (200-2000m)	70%	75%	85%	95%
Short (< 200m)	80%	85%	90%	95%

Field Application Efficiency (Brouwer et al., 1989a)

Irrigation methods	Field application efficiency
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Surface Conveyance Efficiency (Brouwer et al., 1989a)

SEEDS

- **Asia's Green Revolution was seed driven** and occurred in a similar **small-holder dominated** setting. (Otsuka and Larson, 2013)
- **Maize hybrids** have already shown great promise in Africa (Gabre-Madhin et al., 2004)
- Seed development needs to focus on and **local partnerships** with small/ medium seed corporations due to the multitude of agro-climate systems and crops grown in the Basin and Africa as a whole (AGRA)
- Improved seed varieties are not only **higher yielding but more drought and pest tolerant** (AGRA)

SOIL FERTILITY & FERTILIZATION

- **Inorganic fertilizers** must be used to **restore soil nutrients**, and will be spurred by farmer education and training, increased local availability, and reduced prices. (Nziguheba et al., 2010)
- More data on **soil type and chemical properties** would aid in the appropriate application of inputs (Nziguheba et al., 2010; Berazneva et al., 2016)
- Successful techniques for **erosion reduction and soil moisture retention** include terracing, grass buffers, contour bunds, and conservation tillage to reduce erosion and downstream sedimentation (Mati, 2005)

THE CURRENT SITUATION

	Productivity	Fertilizer	Water Use Efficiency
Egypt	High	**Excessive**	Deficient
Ethiopia	Below Average	Low	Deficient
Sudan	**Low**	**Very Low**	Deficient

LOOKING AHEAD

Egypt:

- ✦ Expand adoption of efficient irrigation technologies
- ✦ Export production knowledge and inputs (fertilizer) to other basin countries
- ✦ Reduce cultivation of water intensive crops such as rice, wheat, and sugarcane and increase cultivation of more drought resistant crops such as groundnuts and sorghum (Davis et al., 2017, FAO Egypt CPF, Brouwer et al., 1989b, Brouwer and Heibloem, 1986)

Ethiopia:

- ✦ Continue to increase fertilizer consumption as well as introducing new seed varieties
- ✦ Implement storage and supplemental irrigation

Sudan:

- ✦ Expand irrigation and improve efficiency in large schemes
- ✦ Introduce fertilizer and new seed varieties

REFERENCES

- FAO AQUASTAT (2016). Retrieved April 25, 2018 from the Egypt AQUASTAT profile. http://www.fao.org/nr/water/aquastat/countries_regions/EGY/
- FAO AQUASTAT (2015). Retrieved April 25, 2018 from the Sudan AQUASTAT profile.. http://www.fao.org/nr/water/aquastat/countries_regions/SDN/
- FAO AQUASTAT (2016). Retrieved April 25, 2018 from the Ethiopia AQUASTAT profile.. http://www.fao.org/nr/water/aquastat/countries_regions/ETH/
- FAO (2018). Country Profiles: Ethiopia. Retrieved April 25, 2018 from http://www.fao.org/countryprofiles/index/en/?iso3=ETH
- FAO (2018). Country Profiles: Egypt. Retrieved April 25, 2018 from http://www.fao.org/countryprofiles/index/en/?iso3=EGY
- FAO (2018). Country Profiles: Sudan. Retrieved April 25, 2018 from http://www.fao.org/countryprofiles/index/en/?iso3=SDN
- FAOSTAT (2017). Country Indicators Database: Ethiopia. Retrieved April 25, 2018 from http://www.fao.org/faostat/en/#country/238
- FAOSTAT (2017). Country Indicators Database: Egypt. Retrieved April 25, 2018 from http://www.fao.org/faostat/en/#country/59
- FAOSTAT (2017). Country Indicators Database: Sudan. Retrieved April 25, 2018 from http://www.fao.org/faostat/en/#country/276
- FAO (2018). FAO Egypt launches water management and irrigation project in collaboration with MWRI and MALR. http://www.fao.org/neareast/news/view/en/c/1111170/
- USDA FAS (2016). World Agricultural Production. Circular Series WAP 12-16. http://usda.mannlib.cornell.edu/usda/fas/worldag-production//2010s/2016/worldag-production-12-09-2016.pdf
- USDA FAS (2013). World Agricultural Production. Circular Series WAP 12-13. http://usda.mannlib.cornell.edu/usda/fas/worldag-production//2010s/2013/worldag-production-12-10-2013.pdf
- FAOSTAT (2017). Pesticides Use: Egypt (Data used for 2014), Ethiopia (Data used for 2010), Sudan (Data used for 2012). Retrieved April 25, 2018 from http://www.fao.org/faostat/en/#data/RP/visualize
- FAOSTAT (2017). Crop Yield Data (2014-2016 Avg.) for Various Crops/Countries. Retrieved April 25, 2018 from http://www.fao.org/faostat/en/#compare
- FAOSTAT (2017). Fertilizer Trade: Egypt (Data used for 2014), Ethiopia (Data used for 2014), Sudan (Data used for 2012). Retrieved April 25, 2018 from http://www.fao.org/faostat/en/#data/RV/visualize
- OEC (2016). Country Profile: Egypt. Observatory of Economic Complexity. https://atlas.media.mit.edu/en/profile/country/egy/; https://atlas.media.mit.edu/en/visualize/tree_map/hs92/export/egy/show/3102/2016/
- FAO Aquastat (2015). Breakdown of equipped irrigation area type (latest values available). http://www.fao.org/nr/water/aquastat/data/query/results.html?regionQuery=true&showCodes=false&yearRange.fromYear=1958&yearRange.toYear=2017&varGrpIds=4308%2C4309%2C4310%2C4311&regIds=9805%2C9806%2C9807%2C9808%2C9809&query_type=IRRpage&newestOnly=true&showValueYears=true&categoryIds=-1&XAxis=VARIABLE&showSymbols=true&hideEmptyRowsColoumns=true&lang=en
- Salman M.A. Salman (2011) The new state of South Sudan and the hydropolitics of the Nile Basin, Water International, 36:2, 154-166, DOI: 10.1080/02508060.2011.557997

REFERENCES CONTINUED

- Brouwer, C., Prins, K., & Heibloem, M. (1989a). *Annex I: Irrigation Efficiencies in Irrigation Water Management: Irrigation Scheduling, Training Manual No. 4*. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/docrep/t7202e/t7202e08.htm
- Brouwer, C., Prins, K., & Heibloem, M. (1989b). *Chapter 2: The Influence of Water Shortages on Yields in Irrigation Water Management: Irrigation Scheduling, Training Manual No. 4*. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/docrep/t7202e/t7202e05.htm#2.1%20which%20crops%20are%20sensitive%20to%20water%20shortages
- Brouwer, C. & Heibloem, M. (1986). *Part II, Chapter 3: Crop Water Needs in Irrigation Water Management: Irrigation Water Needs, Training Manual No. 3*. Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/docrep/s2022e/s2022e07.htm#chapter%203:%20crop%20water%20needs
- World Bank (2018). World Bank Development Indicators via FAO: Cereal Yield (kg/ha harvested land). Retrieved April 25, 2018 from https://data.worldbank.org/indicator/AG.YLD.CREL.KG
- Rockstrom, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., & Qiang., Z. (2010). Managing water in rainfed agriculture - the need for a paradigm shift. *Agricultural Water Management*, 97:543-550. doi:10.1016/j.agwat.2009.09.009
- Zeitoun, M., Allan, J. A., & Mohieldeen, Y. (2010). Virtual water 'flows of the Nile Basin, 1998-2004: a first approximation and implications for water security. *Global Environmental Change*, 20, 229-242. doi:10.1016/j.gloenvcha.2009.11.003
- Hengsdijk, H., Smit, A. A. M. F. R., Conjin, J. G., Rutger, B., &Biemands, H. (2014). Agricultural crop potentials and water use in East Africa. Plant Research International, Technical Report 555. https://www.researchgate.net/publication/264346877
- Davis, K. F., Rulli, M. C., Seveso A., & D'Odorico, P. (2017). Increased food production and reduced water use through optimized crop distribution. *Nature Geoscience*, 10:919-924. doi:10.1038/s41561-017-0004-5
- FAO RNE (2015). Towards a regional collaborative strategy on sustainable agricultural water management and food security in the Near East and North Africa region. Food and Agriculture Organization of the United Nations, Regional Initiative on Water Security, Main Report, Second Edition.
- Gabre-Madhin, E. Z., & Haggblade, S. (2004). Successes in African Agriculture: Results of an Expert Survey. *World Development*, 32(5):745:766. doi: 10.1016/j.worlddev.2003.11.004
- Alliance for a Green Revolution in Africa (AGRA) (2014). Planting the seeds of green revolution in Africa. https://reliefweb.int/sites/reliefweb.int/files/resources/agrapassreporthires.pdf
- Oweis, T., & Hachum, A. (2006). Water harvesting and supplemental irrigation for improved water productivity of ry farming systems in West Asia and North Africa. *Agricultural Water Management*. 80, 57-73. Doi: 10.1016/j.agwat.2005.07.004
- Kucharik, C. & Ramankutty, N. (2005). Trends and variability in U.S. corn yields over the twentieth century. Earth Interactions, 9(1), 1-29. Doi: 10.1175/EI098.1

REFERENCES CONTINUED

- Mati, B. M. (2005). *Overview of water and soil nutrient management under smallholder rainfed agriculture in east Africa*. Working Paper 105. Colombo, Sri Lanka: International Water Management Institute (IWMI). http://ageconsearch.umn.edu/bitstream/92406/2/WOR105.pdf
- Berazneva, J., McBride, L., Sheahan, M., & Guerena, D. (2016). Perceived, measured and estimated soil fertility in East Africa: Implications for farmers and researchers. Selected Paper prepared for presentation at the 2016 Agricultural & Applied Economics Association Annual Meeting, Boston, Massachusetts, July 31-August 2.
- Otsuka, K., & Larson, D. F. (eds) (2013). *An African Green Revolution: Finding Ways to Boost Productivity on Small Farms*. The International Bank for Reconstruction and Development/The World Bank.
- Nziguheba, G., Palm, C. A., Berhe, T., Denning, G., Dicko, A., Diouf, O., Diru, W., Flor, R., Frimpong, F., Harawa, R., & et al., (2010). The African Green Revolution: Results from the Millennium Villages Project. *Advances in Agronomy*, 109,75-115. Doi: 10.1016/S0065-2113(10)09003-6
- Cascao, A. E. , and Alan, N. (2016). *Sudan, 'kingmaker' in a new Nile hydropolitics in Land And Hydropolitics in the Nile River Basin: Challenges and New Investments.*
- Cascao, A. E. (2017). *Food, Fodder and Flowers: the critical role of global and regional virtual water trade in the Nile Basin*. Conference Proceedings from the Nile Basin Development Forum, Kigali, 23 October 2017.
- FAO (2013). FAO Statistical Yearbook 2013: World Food and Agriculture. http://www.fao.org/docrep/018/i3107e/i3107e00.htm
- FAO (2014). FAO Statistical Yearbook 2014: Africa Food and Agriculture. http://www.fao.org/3/a-i3620e.pdf
- FAO (2015). FAO Statistical Pocketbook 2015: World Food and Agriculture. http://www.fao.org/documents/card/en/c/383d384a-28e6-47b3-a1a2-2496a9e017b2/
- FAO CPF (2015). Country Programming Framework (CPF) for Sudan. Plan of Action (2015-2019): Resilient Livelihoods for Sustainable Agriculture, Food Security and Nutrition. http://www.fao.org/3/a-i4785e.pdf
- FAO CPF (2013). Country Programming Framework (CPF) Government of Egypt 2012-2017. http://www.fao.org/3/a-bp605e.pdf
- FAO CPF (2017). Country Programming Framework (CPF) for Ethiopia 2016-2020. http://www.fao.org/3/a-i7527e.pdf
- Nile Basin Initiative (2012). Chapter 5: Agriculture in *State of the Nile Basin Report*. http://nileis.nilebasin.org/content/state-river-nile-basin-report
- Nile Basin Initiative (2016). The Nile Basin Water Resources Atlas. http://nileis.nilebasin.org/content/nile-basin-water-resources-atlas
- USDA (2014). 2012 Census of Agriculture. USDA, Volume 1, Geographic Area Series, Part 51. National Agricultural Statistics Service. Page 26. Table 36. https://www.agcensus.usda.gov/Publications/2012/Full_Report/Volume_1,_Chapter_1_US/usv1.pdf